

DECEMBER 2025 | VOLUME 05 | ISSUE 12

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

AgriGate

GROW WITH EVERY PAGE!

An International Multidisciplinary Monthly e-Magazine



23 December
National
FARMER'S
Day

We thank and salute our hardworking Farmers
and wish for prosperity to all on this day



[agrigatemagazine](#)



agrigatemagazine@gmail.com



AgriGate

From the Desk of Editor-in-chief

December 2025|Vol. 5 |Issue No. 12



I would like to introduce the launch of **“AgriGate - An International Multidisciplinary Monthly e-Magazine Volume 05 Issue No. 12 – December 2025”** with immense pleasure our team is privileged to dedicate this issue to the farmers. Farmer's Day in India or **National Farmer's Day** is celebrated on 23rd December across the country to commemorate the birth anniversary of the former Prime Minister Chaudhary Charan Singh. **World Soil Day** is observed on 5 December to raise awareness about the importance of soil, healthy ecosystems, and human well-being. On this day various events, seminars, functions, and competitions are organized on agriculture and its importance to educate and provide knowledge to the people.

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.

A handwritten signature in black ink, appearing to read 'R. Shiv Ramakrishnan'.

Dr R Shiv Ramakrishnan
Editor-in-chief
AgriGate Magazine

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

Volume: 05 Issue No: 12

INTEGRATED NUTRIENT MANAGEMENT (INM) FOR SUSTAINABLE CROP PRODUCTION AND IMPROVE SOIL HEALTH

Article ID: AG-VO5-I12-01***P C Bairwa, R S Meena, R Sammauria, O P Meena, Rajesh and J Singh**

Sri Karan Narendra Agriculture, University, Jobner, India

*Corresponding Author Email ID: pcdfrs@yahoo.com

Introduction

The main challenges facing agriculture planners and farming decision makers in the coming few years' lies in vision world without hunger and zero poverty intensified by rising standards of living of rural regions, where the majority of poor people live and their full dependence on agriculture for living to fulfil their food demands. The key to eliminate the current suffering lies in the creation of a strategic plan that enhances prosperous farming and enables farmers themselves to achieve agricultural growth, reduce poverty, and sustain high returns. Thus, the main challenge in the forthcoming few years lies in the following question. Can agriculture provide the world population with all food needs which are expected to exceed. With the view of an increase in land scarcity and water shortage, most of the agriculture plans depend on the use of chemical fertilizers and the production of new high-yielding crop varieties.

Yet, both components are much expensive and will lead to higher pressure and more responsibilities for the financial investments and consequently will lead to an increase in the total costs. Meanwhile, the price of fertilizers increases, year by year, due to the higher amount of fertilizers needed in the second and third seasons as compared with that in the first season to maintain the current yield production at economical level. Despite the increase in the quantity of fertilizer application, a part of applied fertilizers and soil native nutrients were already consumed by the current and previous crops, especially in the case of intensive agriculture, where two to three crops are annually cultivated. Moreover, application of inorganic fertilizers is not a pragmatic option for many poor farmers in different regions worldwide, because many poor farmers do not have enough money to pay the claim of fertilizer price, besides its scarcity and

un-availability in times of need. Since ancient times, farmers have known that soil health can be restored by applying organic manure; accordingly, they used to apply farmyard manure regularly and directly after crop harvest. Consequently, the custom of using organic manures after harvesting has been coupled with restoration of soil health and improvement of physical, chemical, and biological properties of soil, particularly in marginal soils, which are already suffering from low organic matter and low native nutrient content, low productivity, and limitations and unavailability of essential nutrients.

Additionally, the organic farming system provides organic food, which is preferred by many customers regardless of higher prices. In this context, organic fertilizers, also due to their slow release, have greater residual effect on subsequent crops than inorganic nutrient, which is quickly lost by water leaching and run-off to underground water. Recently escalated calls emerged invited farmers and agriculture specialists to change their awareness towards substituting a part of inorganic fertilizers by cheaper, more sustainable, higher nutrient use of efficient, and eco-friendly nutrients, which are originated from natural resources (Compost), under the bold title of using integrated nutrient management (INM). Thus, the recycling of organic wastes, by the farmers themselves, may be a valuable and acceptable option for many of agriculture planners and numerous farmers to overcome the traditional methods of organic waste disposal, with or without the slight risk to the plants, groundwater or ecological pollution, and human health to achieve the best use of existing natural resources.

The key component of the INM goal is to reach the most effective and homogeneous combination that could lead to good management and be an effective target of the fertilizers, sufficient and balanced use of their quantity and quality, and be straightforwardly up-taken by plants for higher yield without jeopardizing soil native nutrients or polluting the environment. It is ultimately viable to achieve such a target through the wise application of integrated nutrient management (INM) approach, which is known as a balanced mixture of organic, inorganic, and bioorganic microorganisms in combinations in different practices. Also, it can improve all the characteristics of molecule absorption of macronutrients (NPK) and micronutrient inputs. In addition, it can match the crop nutrient requirements and alleviate the constraints of nutrient. Integrated nutrient management is also described as the technique of using minimum effective dose of sufficient and balanced quantities of organic and inorganic fertilizers in combination with specific microorganisms to make nutrients more available and most effective for

maintaining high yields without exposing soil native nutrients and polluting the environment. Furthermore, many benefits can also be gained from using integrated nutrient management. INM can act as the driving forces, able to support the plans of converting marginal lands into productive ones, therefore fulfilling the strategy agenda of increasing cultivated land.

Definition of Integrated Nutrient Management

Integrated nutrient management is a practice where all sources of nutrients namely organic, inorganic and bio fertilizer can be combined use for improving soil health, get good quality yield and maintain ecology and environment. or Integrated nutrient management mean combined application of different sources of plant nutrients like organics, inorganics and bio fertilizers for sustainable crop production without degrading the natural resources on long terms basis.

The key component of INM system includes the following items:

- (1) Considerable attention must be focused on all possible nutrient sources that can be used as a tool of nutrient sources in planning nutrient input programs for optimizing nutrient use efficiency and high yield production
- (2) The forms and quantities of soil nutrient contents in the root zone, which is known as soil balance and its availability to cover crop requirements (spatially and temporally)
- (3) Minimizing nutrient losses, especially in the intensive agriculture system.
- (4) Taking all factors affecting the plant/nutrient relationship into consideration to achieve high yield production, which is the main objective and the major gain of the application of integrated nutrient management (INM), water use efficiency, grain superiority, high economic return, and sustainability.

1. Concepts:

Integrated nutrient management is a practice that combines old and modern techniques of fertilizer use and nutrient management. The idea of INM depends on a number of factors, including harmony in nutrient properties, a balance between crop nutrient demands, what sort of nutrient, in general, is available in soil and in the farmer's hand, information and skills about the most suitable nutrient can be harmonized in combination, and which materials can be safely used that lead to increase nutrient-use efficiency. Additionally, it is a method and a way of disposing organic wastes safely and also an effective method of recycling wastes into good quality compost. The key components of the INM concept include the following: increasing the farmer's

awareness about the valuable use of INM practices, inviting them to forget the excessive use of chemical fertilizers, and encouraging them to focus on long-term plan for sustainable agriculture. Moreover, farmers must have greater consideration for environmental impacts and producing safety food rather than only focusing on profit, which can be obtained. It must always be remembered that food safety is much preferred by many customers, regardless of the price, and it can raise the farmer's returns by following such practices.

2. Objectives:

The main objective of the integrated nutrient management is to maintain economic yield for a long period with little effect on native soil fertility and environmental pollution, making some changes in farmer's awareness toward the eco-friendly technique (organic farming system) for producing healthy food free from contaminants and insuring satisfactory economic returns.

3. Constraints:

Soil corrosion, mining, degradation, and also loss of fertility are the main reasons leading to irreversible decrease of plant production and huge damage for sustainable agriculture. Therefore, to sustain soil health and return soil productivity is an urgent need to overcome the problem of low soil productivity. Serious efforts have been made including the promotion of more productive use of integrated nutrient management, which is an inessential portion in the organic farming system. In addition, considerable attention must be given to determine soil nutrient balance including nutrients absorbed by the current crop accompanied by great attention towards the requirement of the succeeding crop. Thus, continual assessment of the changes in the current soil fertility is necessary to determine nutrient loss through crop absorption, erosion, and leaching and to mirror soil balance, because quick depletion of soil fertility and reduction in soil organic matter will be expected. Additionally, there are some constraints facing the progress of the integrated nutrient management.

Firstly, due to the difficulties in obtaining FYM and bio fertilizers, some poor farmers have some trouble in obtaining organic manure as well as lack of knowledge, poor advisory services, and skills of recycling organic wastes to produce high quality compost. Also, biotic or abiotic stresses are ranked to second series and the third will be the poor tillage, whereas the lack of equipment was ranked in the fourth succession. Also, the absence of the role of extension services and NGOs to support farmers and direct their attention to the importance of using

integrated nutrient management and its benefits in conserving soil properties, soil nutrient balance, environmental impacts, and their role in increasing their profitability is a constraint.

4. Advantages:

Preparing the soil for producing its maximum capacity is an important target and a complex process resulting from the solidarity of many factors, which largely depend on more than one factor to get the best benefits, among others, soil nutrient content which must not only be in an appropriate and accurate quantity but also be in an easy and available form for plant absorption at the right time of plant requirement. Thus, a good nutrient management package is a way to attain ideal growth and yield levels for most crops at different agro-ecological zones, with or without minimum risk in the environment (eco-friendly strategy). This can also be described as a system involving a series of the following benefits:

- (1) Systems can improve the soil nutrient natives and increase the solubility and availability of fertilizers to be used.
- (2) Use the harmonious behaviour of nutrient supplies and making them match with the crop requirements.
- (3) Offer the nutritional balance to the crops and lessen the aggressive effects resulting from the opposite impact between nutrient fractions and nutrient imbalance.
- (4) Advance and sustain the physiochemical and biological functions of soil properties
- (5) Reduce the rate of soil degeneration, water, and ecosystem by enhancing carbon confiscation and decreasing nutrient losses to ground and surface water forms and/or to environment pollution.
- (6) Minimize higher total costs of production and raise the farmer's returns (increasing profitability).
- (7) Improve the resistance to both biotic and abiotic stresses.
- (8) An effective method of agricultural practices to ensure healthy food, covering population food demands alongside with many soil and environmental impacts, especially in countries with rapid growth in population.
- (9) Additional benefits can also be gained; it does not only save the total costs at the satisfactory level with an increase in crop production but also can be easily practiced by farmers; therefore, it is considered one of the most promising techniques in line with the future needs.
- (10) INM can have positive effects on the susceptibility or plant resistance against many types of biotic and abiotic stresses.



(11) Following INM will enable to explore a larger volume of soil in order to access water and nutrients; additionally, improved root development enables the plant to absorb water from deeper soil layers and then reflect an increase in the ability of crops toward drought resistance.

(12) Changes in awareness of farmers toward the climate changes from season to season, which have greater ecological impacts in order to produce safe food rather than achieving higher yield aiming at attaining higher profit.

FEASTING ON FIRE: THE BATTLE FOR INDIA'S FOOD SECURITY IN A WARMING WORLD

Article ID: AG-VO5-I12-02*** Dr. Sethupathi N**

NITI Aayog, India

*Corresponding Author Email ID: sethu21iari@gmail.com

Introduction

Agriculture is not just an economic activity in India — it is a way of life. It employs nearly 50% of the population and contributes significantly to the country's GDP. But today, every farmer's harvest depends on something increasingly unpredictable: the climate. From delayed monsoons to scorching heat, climate change is turning farming into a gamble — and the stakes include India's food security, rural livelihoods, and national economy. In June 2019, the thermometer in Churu, Rajasthan, hit a blistering 50.8°C, nearly breaking India's all-time heat record. While city dwellers scrambled for air conditioning, a quieter, more desperate struggle was unfolding in the fields. For the 50 percent of India's population dependent on agriculture, extreme weather is not just an inconvenience; it is an existential threat to their livelihood and the nation's food bowl (Malhi *et al.*, 2021).

As global temperatures threaten to rise between 2°C and 6°C over the 21st century in South Asia, India stands at a precarious crossroad. The country's agricultural sector, which contributes 15.4% to the GDP, is battling a "mega trend" of erratic monsoons, receding glaciers, and scorching heatwaves. This article delves into the science of these threats, the resilience being engineered by Indian scientists and farmers, and the policy roadmap designed to secure the future.

The Assault on Agriculture

Climate change is often visualized as polar bears on melting ice, but in India, it looks like a farmer staring at a withered crop or a dry well. The impacts are sector-wide, affecting everything from soil chemistry to animal physiology.

The Yield Crash: The fundamental math of farming is changing. Scientific assessments predict that by the mid-21st century, crop yields in South Asian countries could decrease by an average of 30% due to climatic shifts. The correlation is stark: a temperature increase of just 1.5°C, combined with a seemingly minor precipitation decrease of 2mm, can slash rice yields by 3% to 15%.

The enemies are diverse. New pathogen complexes are emerging due to altered humidity and temperature profiles, leading to increased pest populations that devastate productivity. Furthermore, extreme events like the super cyclone in Odisha (1999) or the floods in Kerala (2018) and Bihar (2008) have caused immediate, catastrophic losses to standing crops and arable land. The economic toll is staggering: the Government of India estimated annual losses of US\$ 9–10 billion due to adverse climate effects as of 2018 (Srinivasarao et al., 2018).

The Water Paradox:

India is facing a dual crisis of too much water and too little. On one hand, the Himalayan glaciers—the water towers of South Asia—are retreating rapidly. The Gangotri Glacier has retreated three times faster in the last 30 years than in the previous two centuries, threatening the long-term flow of rivers that feed the northern plains (Liaqat *et al.*, 2022). On the other hand, arid regions in Rajasthan and Gujarat face chronic drought, while parts of Central India are projected to see a rainfall reduction of 10–20% during winters by the 2050s.

Livestock and Fisheries under Stress:

The impact extends beyond plants. Animals, much like humans, have a thermal tolerance zone. When temperatures exceed this, their physiology collapses. In dairy cattle, respiration rates spike, and blood flow changes to dissipate heat, diverting energy away from milk production. Heat stress significantly reduces feed intake in poultry, leading to lower body weight and thinner eggshells.

Fisheries are equally vulnerable. A rise of just 1°C can alter fish mortality rates and geographical distribution. In West Bengal and Odisha, the breeding period of Indian major carps has already shifted from June to March due to changing thermal profiles, forcing hatcheries to adapt their entire operational calendars.

Engineering Resilience – "Adaptation-Led Mitigation"

The scientific community in India has realized that we cannot simply "stop" climate change immediately; we must adapt to survive it. This approach is termed "Adaptation-led

Mitigation." It involves adjusting farming practices to cope with climate risks while simultaneously reducing the carbon footprint of agriculture (Bai et al., 2022).

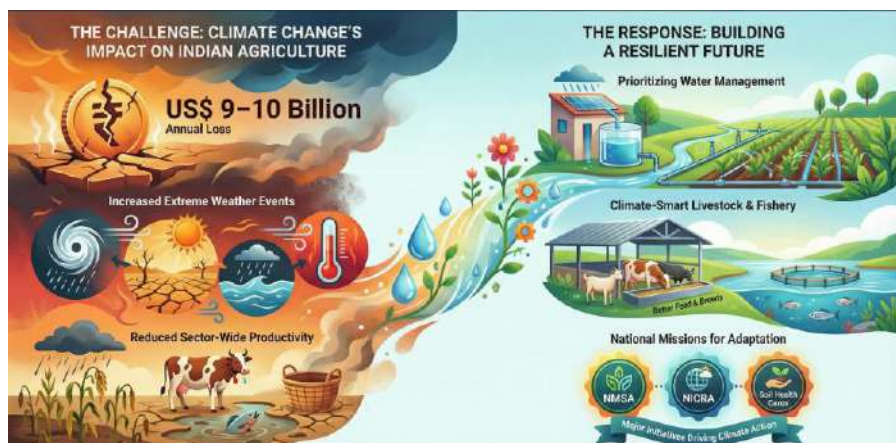


Fig 1. India's Fields of Change: Adapting Agriculture to a New Climate

Water Warriors:

More Crop Per Drop With water becoming the most limiting factor, technologies focus on efficiency. Micro-irrigation and drip systems have shown to increase water use efficiency significantly. By saving water, farmers also save the energy required to pump it, creating a "triple benefit" of water conservation, energy saving, and yield increase. Simple innovations like "ridges and furrows" or "broad bed furrows" in fields help retain soil moisture during dry spells and improve drainage during floods.

The Methane Problem and Livestock:

Agriculture is a victim, but also a contributor to greenhouse gases (GHGs). Livestock enteric fermentation (burps) releases methane, a potent GHG. Indian scientists have found that feed matters. Feeding cattle dry straw produces massive amounts of methane (approx. 6 ml per 100mg digested). However, switching to a diet of fresh tree leaves or cereal grains can cut this emission by nearly two-thirds. Promoting better breeds and shelter management further reduces the environmental footprint while maintaining milk yields (Dash et al., 2016).

Soil Health as a Carbon Sink:

Healthy soil acts as a sponge for both water and carbon. Policies promoting "Neem Coated Urea" act as slow-release nitrogen fertilizers, reducing nitrous oxide emissions (another GHG) and preventing pest infestation. Conservation agriculture techniques, such as zero-tillage (planting without ploughing), help lock carbon into the soil and utilize residual moisture, proving vital for rabi crops in rain-fed areas.

Government Initiatives and Scientific Assessment of Climate Change Impacts on Indian Agriculture

The Government of India recognizes climate change as a critical threat to agricultural sustainability and livelihoods. In response, coordinated multi-location field experiments and simulation-based assessments have been undertaken across diverse agro-climatic regions. These studies have utilized advanced crop growth simulation models integrated with future climate projections for mid- and late-century periods (2050 and 2080).

Model outputs indicate substantial yield reductions under a “no-adaptation” scenario. Rainfed rice production is projected to decline by approximately 20% by 2050 and 47% by 2080, whereas irrigated rice yields may decrease by 3.5% and 5% over the same timeframes (Joshi and Tyagi, 2017). Wheat, another major staple, is anticipated to experience yield losses of 19.3% by 2050 and up to 40% by 2080, showing significant spatio-temporal variability. Kharif maize yields are expected to fall by 18% and 23% in 2050 and 2080 scenarios, respectively. Beyond productivity losses, climate change also diminishes nutritional quality, disrupts cropping cycles, and intensifies the adverse effects of extreme events such as droughts — with direct implications for farm income, household food security, and dietary adequacy.

Policy Responses for Climate-Resilient Agricultural Development

To strengthen agricultural resilience, the Government of India has embedded climate adaptation within its national development framework. Notably, the National Mission for Sustainable Agriculture (NMSA), a key pillar of the National Action Plan on Climate Change (NAPCC), focuses on the promotion of climate-smart farming systems, efficient water and soil management, and risk-reducing agronomic innovations across the country.

Complementing this mission, the Indian Council of Agricultural Research (ICAR) initiated a flagship multidisciplinary programme — National Innovations in Climate Resilient Agriculture (NICRA) — in 2011. NICRA aims to develop, field-test, and accelerate the dissemination of climate-resilient technologies tailored to the specific vulnerabilities of different agro-ecological zones. The initiative addresses both adaptation and mitigation through strategic research on crops, horticulture, livestock, fisheries, and poultry production systems.

Key operational thrusts under NICRA include:

1. Vulnerability Mapping: Identifying districts and regions most susceptible to climatic hazards.

2. Technological Innovations: Breeding and promoting stress-tolerant varieties and climate-smart management practices.
3. Livestock and Fisheries Adaptation: Evaluating climate risks for animal husbandry and aquatic systems, and optimizing resilience-building strategies accordingly.

Outcomes and Technology Deployment

The programme has achieved notable progress. Since 2014, 1,888 climate-resilient crop varieties have been developed, alongside 68 location-specific adaptation and mitigation technologies that have been validated and demonstrated across vulnerable farming communities. These outputs contribute to national capacity for climate-risk preparedness and help safeguard food production systems from emerging climatic uncertainties.

International Diplomacy:

India is not fighting alone. Through the United Nations Framework Convention on Climate Change (UNFCCC), specifically the Koronivia Joint Work on Agriculture (KJWA), India shares its expertise in soil health and water management with the world. The goal is to move from scientific discussion to on-the-ground implementation, acknowledging that agriculture is central to the global climate agenda.

Conclusion: A Call for Integrated Action

The battle against climate change in Indian agriculture is far from over. The road ahead requires a "strategic approach" where central and state plans (NAPCC and SAPCC) operate in perfect synergy.

To secure the future, we must:

1. Reduce Food Loss: Treating food waste reduction as a primary climate mitigation strategy.
2. Incentivize Good Practices: Reward farmers who adopt water-saving and residue-recycling methods.
3. Region-Specific Research: Acknowledge that a solution for the Himalayas won't work for the coastal plains; we need location-specific adaptation research.

References

Bai Ye L., Yang Z. and Wang G. , Impact of climate change on agricultural productivity: a combination of spatial Durbin model and entropy approaches, *International Journal of Climate Change Strategies and Management*, <https://doi.org/10.1108/IJCCSM-02-2022-0016> (2022)

- Dash, S., Chakravarty, A.K., Singh, A., Upadhyay, A., Singh, M. and Yousuf, S. 2016. Effect of heat stress on reproductive performances of dairy cattle and buffaloes: A review. *Vet. World*. 9(3): 235-244.
- Joshi, P.K. and Tyagi, N.K. 2017. Assessment of Government policies and programmes on climate change- Adaptation, mitigation and resilience in South Asian Agriculture. Book Chapter: Agriculture under climate change threats, strategies and policies, section-VI: 431-434
- Liaquat, Barutçular C., Farooq M.U., Ahmad H., Jan M.F., Ahmad Z., Nawaz H. and Li M., Climate change in relation to agriculture: A review, *Spanish Journal of Agricultural Research*, **20(2)**, e03R01, <https://doi.org/10.5424/sjar/2022202-17742> (2022)
- Malhi G.S., Kaur M. and Kaushik P., Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review, *Sustainability*, 13, 1318 (2021)
- Srinivasarao, Ch., Rao, K.V., Gopinadh, KA., Prasad, Y.G. Arunachalam, A., Ramana, D.B.V., Chary, G.R., Gangaiah, B., Venkateswarlu, B. and Mohapatra, T. 2019. Agriculture Contingency Plans for Managing Weather Aberrations and Extreme Climatic Events: Development, Implementation and Impacts in India. *Advances in Agronomy*. <https://doi.org/10.1016/bs.agron.2019.08.002>

Volume: 05 Issue No: 12

THE CHOKEHOLD: UNRAVELLING THE SCIENCE AND STRUGGLE OF DELHI'S 2024 AIR POLLUTION CRISIS

Article ID: AG-VO5-I12-03

*** Dr. Sethupathi N**

NITI Aayog, New Delhi, India

*Corresponding Author Email ID: sethu21iari@gmail.com

Introduction

In the winter of 2024, the residents of Delhi, India, woke up not to the crisp chill of the season, but to a grey, suffocating blanket. The city, often celebrated as the "heart of the country" for its rich history and political significance, found itself making headlines for a much darker reason: it had once again become one of the most polluted cities on Earth. The Air Quality Index (AQI) did not just dip into the "poor" category; it skyrocketed into the "severe" and "hazardous" zones, creating a public health emergency that turned the act of breathing into a health risk. This article explores the anatomy of this environmental crisis, dissecting the chemical composition of the smog, the meteorological traps that hold it in place, the devastation it wreaks on the human body, and the technological and policy battles being fought to clear the air.

The Metrics of Misery: Understanding the AQI

To understand the severity of the 2024 crisis, one must first understand the yardstick used to measure it: the Air Quality Index (AQI). The AQI is a numerical scale that transforms complex scientific data on air pollutants into a color-coded warning system for the public (Khera and Irshad, 2023).

In Delhi, the Central Pollution Control Board (CPCB) utilizes this index to track key pollutants, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ground-level ozone (O_3). However, the most critical protagonists in this tragedy are Particulate Matter: PM10 (particles 10 micrometers or less in diameter) and PM2.5 (fine particles 2.5 micrometers or less). Because of its microscopic size, PM2.5 is particularly insidious; it can bypass the body's natural defenses, penetrating deep into the lungs and entering the bloodstream (Gayen *et al.*, 2022).



Fig 1. Delhi: A Snapshot of Population and Density

In 2024, the numbers were staggering. While an AQI of 0–50 is considered "Good," Delhi regularly saw levels exceeding 400. Specific hotspots like Anand Vihar and Wazirpur recorded AQI levels of 414, placing them firmly in the "severe" category. At these levels, the air is not just unhealthy for sensitive groups; it affects the entire population, necessitating warnings to avoid outdoor activities entirely (Kurmi *et al.*, 2024).

The Science of Measurement

Determining these numbers requires sophisticated technology. The CPCB employs the beta-attenuation mass monitor (BAM), a device that uses Carbon-14 beta radiation to measure particle mass in near real-time. This technology is crucial for capturing sudden surges in pollution, such as those following the Diwali fireworks or massive stubble burning events. However, the science is not without challenges; Delhi's high humidity and construction dust can sometimes inflate these readings by absorbing water or clogging filters, introducing error margins that scientists must constantly account for (Terzano *et al.*, 2010)

The Toxic Cocktail: Anatomy of the Smog

The smog that chokes Delhi is not a single substance but a complex, toxic soup derived from primary and secondary sources.

1. The Primary Culprits: Vehicles and Industry Vehicular emissions remain a dominant force in Delhi's pollution profile. The city's fleet releases a barrage of carbon monoxide, nitrogen oxides, and hydrocarbons. Diesel vehicles, particularly older models and trucks, are significant sources of soot and NO₂ (Tripathi *et al.*, 2019). Despite mandates to scrap 15-year-old vehicles and a

push toward electric vehicles (EVs), the sheer volume of traffic and the persistence of older engines continue to degrade air quality. Similarly, factories and refineries surrounding the National Capital Region (NCR) release sulfur dioxide and heavy metals, contributing significantly to the chemical load of the atmosphere.

2. *The Secondary Sources: The Hidden Dangers* Pollution in Delhi also bubbles up from the ground. Poorly managed landfills release methane, a potent greenhouse gas that contributes to the formation of ground-level ozone. Furthermore, stagnant, untreated water bodies emit hydrogen sulfide and methane, adding to the noxious mix. The open burning of plastic waste releases carcinogenic dioxins and furans, further lacing the air with poisons (Gayen *et al.*, 2022).

3. *The Seasonal Spikes: Stubble and Firecrackers* The crisis reaches its zenith in winter due to specific contributing factors. Agricultural stubble burning in neighbouring states like Punjab and Haryana releases massive plumes of smoke that drift into Delhi. In 2024, despite judicial intervention, enforcement remained a challenge, with the smoke from farm fires mixing with urban pollutants. This is compounded by the celebration of Diwali. Despite bans, the burning of firecrackers releases a concentrated burst of PM2.5 and PM10, causing pollution levels to spike aggressively.

The Winter Trap: Meteorology's Role

Why is 2024's winter so much worse than the summer? The answer lies in meteorology. During winter, "temperature inversion" occurs—a phenomenon where a layer of warm air sits over a layer of cold air near the ground.

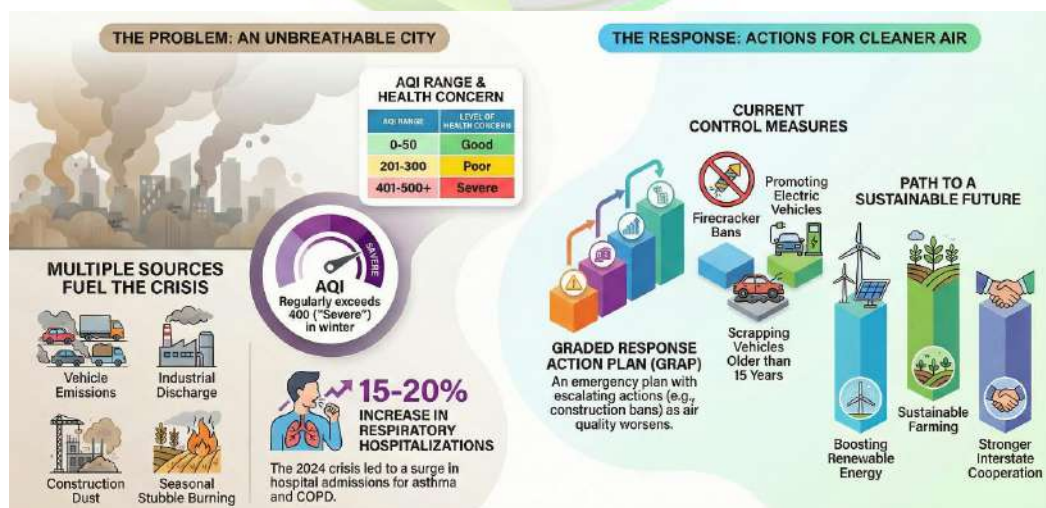


Fig. 2: Delhi's 2024 Air Pollution Crisis: Public Health Emergency

This traps pollutants, preventing them from dispersing into the upper atmosphere. Combined with low wind speeds, this creates a stagnant chamber where smoke, dust, and emissions accumulate to form a thick, blinding smog.

The Human Cost: From Lungs to Bones

The health implications of the 2024 crisis have been catastrophic, affecting nearly every system in the human body.

Respiratory Havoc: The most immediate impact is on the lungs. Hospitals in Delhi reported a 15–20% increase in admissions for respiratory disorders in 2024. Cases of asthma and Chronic Obstructive Pulmonary Disease (COPD) flared up, and doctors noted a rise in "walking pneumonia," a milder but persistent infection attributed to prolonged exposure to toxic air. The fine particulate matter induces oxidative stress and inflammation, damaging lung cells and causing the overproduction of mucus.

Beyond the Breath: Neurodegenerative and Immune Effects: Research has shown that the dangers of PM2.5 extend far beyond the lungs. These particles can cross the blood-brain barrier, leading to neuroinflammation. Chronic exposure has been linked to neurodegenerative disorders like Alzheimer's, Parkinson's, and Multiple Sclerosis.

Furthermore, the smog is affecting the skeletal and immune systems. The thick pollution blocks UV-B radiation from the sun, leading to widespread Vitamin D deficiency in children. This deficiency impairs bone health and suppresses the immune system, leaving the population more susceptible to infections (Lee *et al.*, 2023).

A Crisis for Children: Perhaps the most heartbreaking statistic involves the city's youngest residents. Air pollution is now recognized as the third most common cause of mortality in children under five. In Delhi, approximately 20% of child deaths associated with PM2.5 exposure in the region occur within the city limits. The exposure leads to developmental delays, cognitive impairments, and a lifelong susceptibility to disease.

The Response: Policy, Policing, and Technology

The government's response to the 2024 crisis has been anchored by the Graded Response Action Plan (GRAP), a set of emergency measures triggered by AQI severity.

- **Stage I & II (Poor to Very Poor):** Authorities enforce dust control at construction sites and deploy anti-smog guns.
- **Stage III (Severe):** Construction bans are implemented, and stone crushers are closed.

- **Stage IV (Severe+):** When the AQI exceeds 450, the city enters a lockdown-like state for emissions. Entry of non-essential trucks is banned, schools may be closed, and work-from-home orders are encouraged to take vehicles off the road.

Despite these protocols, enforcement remains a hurdle. While the government seized over 19,000 kg of firecrackers and deployed hundreds of police teams to enforce bans, illegal sales and stubble burning continued in pockets.

International Pressure and Climate Justice: The crisis has also played out on the global stage. At COP29, global health bodies urged India to align its domestic policies with international frameworks like the COP28 UAE Declaration on Climate and Health. India has advocated for "climate justice," arguing that it needs access to affordable pollution control technology and climate finance from developed nations to effectively combat the crisis without stifling its economic growth (Zhang *et al.*, 2022).

The Role of Artificial Intelligence

A beacon of hope lies in technology. In 2024, scientists and policymakers increasingly turned to Artificial Intelligence (AI) to manage the crisis. Advanced machine learning models (such as LSTM and Random Forests) are now being used to predict AQI with greater precision than ever before. These AI systems analyze satellite imagery, traffic flow, and meteorological data to forecast pollution hotspots, allowing for hyper-local interventions.

Conclusion

The air pollution crisis in Delhi is not merely an inconvenience; it is a complex disaster where meteorology, economics, and public health collide. While initiatives like GRAP and the push for renewable energy show promise, the sheer scale of the 2024 crisis underscores the need for stricter enforcement and interstate cooperation. To understand the situation in Delhi, imagine the city as a patient in an intensive care unit. The "medicines" such as electric vehicles, smog towers, and policy restrictions are being administered, but the "virus" viz., a combination of industrial smoke, vehicle exhaust, and farm fires is mutating and adapting, aided by the "weather," which acts as an incubator. Until the source of the infection is treated aggressively and systemically, the patient remains in critical condition.

References

Gayen BK, Dutta D, Acharya P, Sreekesh S, Kulshrestha UC, Acharya N. Exploring the effect of waterbodies coupled with other environmental parameters to model PM_{2.5} over Delhi-

- NCT in northwest India. *Atmospheric Pollut Res.* 2022;13(12):101614. <https://doi.org/10.1016/j.apr.2022.101614>
- Khera G, Irshad SM. From environmental management to risk governance: air pollution case of Delhi, India. *Int J Environ Technol Manag.* 2023;26(1–2):135–52. <https://doi.org/10.1504/IJETM.2023.127332>.
- Kurmi OP, Adhikari TB, Tyagi SK, Kallestrup P, Sigsgaard T. Addressing air pollution in India: Innovative strategies for sustainable solutions. *Indian J Med Res.* 2024;160(1):1. https://doi.org/10.25259/IJMR_691_2024.
- Lee J, Weerasinghe-Mudiyanselage PD, Kim B, Kang S, Kim JS, Moon C. Particulate matter exposure and neurodegenerative diseases: a comprehensive update on toxicity and mechanisms. *Ecotoxicol Environ Saf.* 2023; 266: 115565. <https://doi.org/10.1016/j.ecoenv.2023.115565>.
- Terzano C, Di Stefano F, Conti V, Graziani E, Petroianni A. Air pollution ultrafine particles: toxicity beyond the lung. *Eur Rev Med Pharmacol Sci.* 2010;14(10):809–21.
- Tripathi CB, Baredar P, Tripathi L. Air pollution in Delhi. *Curr Sci.* 2019;117(7):1153–60
- Zhang Y, Liu S, Wang Y, Wang Y. Causal relationship between particulate matter 2.5 and hypothyroidism: a two-sample Mendelian randomization study. *Front Public Health.* 2022;10:1000103. <https://doi.org/10.3389/fpubh.2022.1000103>.

IMPACT OF METABOLIC DISEASE IN DAIRY CATTLE

Article ID: AG-VO5-I12-04**L. Arun¹ and C.Inbaraj^{2*}**¹Assistant Professor, Department of Veterinary Animal Husbandry Extension,²Assistant Professor, Department of Veterinary Medicine,

Veterinary College and Research Institute, Udumalpet – 642 205, TANUVAS, India

*Corresponding Author Email ID: vetinba@gmail.com

Introduction

Metabolic disorders are a key problem in the transition period of dairy cows as the cow suffers from negative energy balance due to low dry matter intake. Main challenge and problem appear to be adaptation of rumen at different physiological stages, which leads to onset of various metabolic diseases. Nutrition plays a pivotal role in preventing metabolic disorders post calving and through lactation. Metabolic disorders such as ketosis, fatty liver syndrome, hypocalcemia etc can have a significant effect not only on a cow's lactation performance, but also on fertility performance. These ailments affect cattle and are brought on by production techniques when the body's energy, calcium, or magnesium stores are insufficient to fulfill metabolic demands.

They play a major role in environments that demand high animal productivity, such as the dairy sector. Metabolic illnesses in cattle include hypomagnesemia, milk fever, ketosis, and fat cow syndrome. The key to preventing these diseases in cows is to make dietary corrections during the late pregnancy and peak lactation phase. It is imperative to obtain competent veterinary and dietary assistance if these disorders are prevalent. So, an understanding and day to day update of these metabolic diseases becomes essential and critical for successful venture of dairy farm.

Parturient Paresis (Milk Fever):

Parturient paresis is a metabolic illness that typically strikes adult females within 72 hours of giving birth. It is often found in Jersey cows that give a lot. Cattle that are older and

more mature, typically in the 5–10 year age range, are more likely affected. The condition primarily affects high yielding dairy cows, particularly in the third, fourth, or fifth trimester of pregnancy or delivery. Muscle tremors and recumbency are the hallmarks of this, which goes away after ingesting calcium borogluconate.

Causes:

A decrease in tissue fluids' ionized calcium content. excessive calcium loss in the milk immediately following delivery. excessive calcium loss in the colostrum that exceeds the body's ability to mobilize calcium from the bones and absorb it from the gut. a decrease in the intestinal absorption of calcium during parturition. Deficiency of Vit. D and less acidic pH in stomach. It's possible that the skeleton's calcium reserves won't be released quickly enough to keep serum levels normal. Hypophosphatemia and Hypomagnesaemia can occasionally be linked to milk fever. If the animal experiences stress of any kind, there is a particular vulnerability. Exercise that is forced, lengthy travel, abrupt food deprivation, and grazing on plants that contain oxalate or green cereal crops.

Clinical Signs:

- There is muscle weakness and flaccidity of muscles.
- Tremor is found in the eye and muzzle.
- There is diminished consciousness and the animal may show drowsy condition.
- There is lateral kink in the neck or head may rest on the flank ('S' shaped posture).
- The skin and the extremities remain cold. Temperature is generally subnormal.
- Muzzle becomes dry and dilated pupil.
- There is relaxation of anus.
- Venous pressure is low as such it may difficult to raise the jugular vein.
- There is atony of the rumen leading to constipation anuria due to bladder atony.
- The animal may be in lateral placement or Sternal recumbency

First Aid:

Prior to the cow being comatose, tend to the animals as soon as feasible. Until assistance arrives, place the animal in sternal recumbency. Transfer the cows from locations with slick floors to those without. Build a temporary shelter to shield the animals from the sun if they are laying in the open.

See a licensed veterinarian right away for calcium administration if there are indications of milk fever and recumbency.

Prevention Methods:

To avoid milk fever in the final two weeks before calving, feed a diet with fewer than 20 grams of calcium per day. Aim to limit your calcium consumption when it's dry. To avoid milk fever, a diet with less than 80 to 100 grams of calcium per day may be given during the dry season. A daily intake of fewer than 35 grams of phosphorus may be the recommended threshold to prevent milk fever. In order to avoid milk fever in the final month of pregnancy, it may be possible to maintain high phosphorus and low calcium levels (Ca: P= 1:3.3).

Diets with higher levels of sulfur and chloride anions than potassium and sodium cations may be able to prevent the development of certain diseases. Overabundance of anions facilitate calcium absorption. Three weeks prior to delivery, ammonium chloride administration might be a helpful preventative measure.

Preventing milk fever has proven to be an effective strategy when using vitamin D3 and its metabolites. One intramuscular injection at a dose of 10 million units may be given three to eight days before delivery. One million units of medication for every 45 kg of body weight would be a sensible prophylactic measure. To avoid milk fever, oral calcium gel dose (50% calcium chloride) has been recommended before calving, during calving, 12 hours after calving, and 24 hours after calving. This condition can be avoided by adding lime stone water to the drinking water before giving birth. Pregnancy is not the time to overeat.

Ketosis:

An increased level of ketone bodies (acetone, acetoacetate, and beta-hydroxybutyrate) in the blood is known as hyperketonemia. While ketosis is a clinical condition linked to more severe hyperketonemia, hyperketonemia frequently occurs without any clinical symptoms. Anorexia, decreased milk supply, a significant loss of body condition, firm dry stools, and, rarely, neurological indications (nervous ketosis) are important clinical signs of ketosis. Other signs are less clear. Regular testing with suitable cow side tests of blood (hyperketonemia), milk (hyperketolactia), or urine (hyperketonuria) can identify cows with increased ketone bodies. The best course of action for treating hyperketonemia is to take propylene glycol orally.

Clinical Signs:

- Drop in milk yield.

- Slight reduction in feed intake.
- Depression / lethargy.
- Weight loss.
- Particular acetone smell (fruity odour) in breath.
- Fever.
- Abnormal gait, humped back posture, head/muzzle pressing.
- Pica, biting of coarse surfaces.
- Nervous signs, circling, staggering and falling.

Prevention:

During later part of gestation

- Adequate feeding.
- Excess feeding of energy rich concentrates should be avoided.
- The animal should be given proper exercise during this stage.

After calving when the milk yield increases suddenly

- The animal must be provided with adequate amount of energy rich concentrate feed according to the milk yield.
- Sudden change of feed should be avoided.
- High yielding animals can be fed with By pass fat to at a rate of 15 - 20g/kg milk yield to prevent negative energy balance.
- Sodium Bicarbonate may be incorporated in feed to prevent development of acidosis due to excess concentrate feeding.
- Probiotics, Vitamin and mineral supplements should be included in the feed during the entire peak lactation period in order to improve feed utilization and metabolism.
- The feed containing high quantity of urea and silage should be avoided in susceptible animals.
- Disease conditions like retention of placenta (ROP), metritis, mastitis and environmental stress etc should be treated immediately.
- Regular weekly tasting of urine and milk samples up to 2 months after calving can help in early detection of ketosis and immediate treatment should be given to save the animal.

Volume: 05 Issue No: 12

B-1,3-GLUCANASES: PLANTS' MOLECULAR SHIELD AGAINST PATHOGENS

Article ID: AG-VO5-I12-05

**Sri Meenakshi Sundaram K.V., Mohana Priya S., Samuel P., Deepa G., Akilan M.,
Anuradha C.***

ICAR-National Research Centre for Banana

Thogamalai Road, Thayanur Post, Tiruchirappalli - 620 102. Tamil Nadu, India.

*Corresponding Author Email ID: anuradha.chelliah@gmail.com

Introduction

Plants, as sessile organisms, are constantly exposed to a wide spectrum of microbial pathogens, including fungi, bacteria, nematodes, and viruses. To survive in such dynamic environments, they have evolved highly sophisticated and multilayered immune systems comprising both constitutive and inducible defense mechanisms (Balasubramanian et al., 2012; Bari and Jones, 2009; Couto and Zipfel, 2016; Dos Santos and Franco, 2023). These defense strategies enable plants to perceive potential threats, activate intracellular signaling cascades, reinforce structural barriers, and deploy antimicrobial compounds, thereby safeguarding plant fitness and productivity (Riseh et al., 2023a; Yu et al., 2022).

Among the diverse repertoire of defense-related proteins, β -1,3-glucanases (EC 3.2.1.39) constitute a major class of pathogenesis-related (PR-2) proteins that play essential roles in plant innate immunity. These enzymes are widely distributed in higher plants and are typically induced under biotic stress conditions (Balasubramanian et al., 2012; Velásquez-Zapata et al., 2023; Jiang et al., 2024a). β -1,3-glucanases hydrolyze β -1,3-glucans, key structural polysaccharides in fungal cell walls, leading to the degradation and lysis of invading pathogens (Perrot et al., 2022a; Riseh et al., 2023b). Their enzymatic activity not only suppresses fungal growth directly but also generates β -1,3-glucan oligosaccharides that function as potent elicitors. These elicitors activate downstream defense pathways, including salicylic acid (SA)-mediated signaling, reactive oxygen species (ROS) production, systemic acquired resistance (SAR), and the expression of additional PR proteins (Perrot et al., 2022b; Fu and Dong, 2013; Miedes et al., 2019).

Beyond pathogen defense, β -1,3-glucanases are multifunctional enzymes implicated in several developmental processes. They are involved in cell wall remodeling during cell division and expansion, pollen germination and tube growth, seed germination, fruit ripening, somatic embryogenesis, and floral development (Balasubramanian et al., 2012; Dos Santos and Franco, 2023; Jiang et al., 2024b). Although their basal expression in healthy tissues is generally low, β -1,3-glucanase genes exhibit strong up-regulation following pathogen attack or exposure to stress hormones such as salicylic acid, jasmonic acid, and ethylene, highlighting their importance as inducible components of the plant defense system (Van Loon et al., 2006; Dos Santos & Franco, 2023).

Structural Characteristics of Plant β -1,3-Glucanases

β -glucans are widespread structural polysaccharides found in the cell walls of diverse organisms, including bacteria, fungi, algae, and higher plants. These polymers are composed of D-glucose monomers linked through β -1,3, β -1,4, and/or β -1,6 glycosidic bonds, with the precise linkage pattern varying depending on the biological source (Riseh et al., 2023a; Brown and Gordon, 2005). Among these, β -1,3-glucans form the backbone of fungal cell walls, making them key molecular targets for plant defense enzymes.

β -1,3-glucanases specifically catalyze the hydrolysis of β -1,3-D-glucosidic linkages in β -1,3-D-glucans, thereby compromising the structural integrity of fungal hyphae (Jiang et al., 2024c; Sels et al., 2008). As members of the pathogenesis-related protein family 2 (PR-2), these enzymes contribute to plant innate immunity by directly degrading pathogen-associated glucans and by generating bioactive oligosaccharides that act as elicitors of downstream defense pathways (Yang et al., 2018; Lagaert et al., 2014).

The structural characteristics of β -glucans themselves vary considerably across taxa. β -glucans extracted from cereals such as barley, wheat, and rice typically consist of mixed β -1,3/ β -1,4 linkages and possess high molecular weight and viscosity, whereas fungal and yeast β -glucans are enriched in β -1,3 linkages with β -1,6 branches (Riseh et al., 2023b; Vetvicka and Vetvickova, 2020). Their localization in cell walls and aleurone layers underscores their protective and structural roles. The physicochemical diversity of β -glucans influences substrate specificity, catalytic efficiency, and functional diversity of β -1,3-glucanases across plant species.

In plants, β -1,3-glucanases are widely distributed in species such as barley (*Hordeum vulgare*), soybean (*Glycine max*), grapevine (*Vitis vinifera*), and tobacco, where they play key defensive roles against fungal pathogens (Jiang et al., 2024a; Balasubramanian et al., 2012; Kriznik et al., 2017). Beyond their antimicrobial properties, these enzymes also participate in fundamental physiological processes, including cell wall remodeling, regulation of plasmodesmatal permeability, pollen germination and tube growth, embryogenesis, seed germination, and responses to abiotic stress (Levy et al., 2007; Benitez-Alfonso et al., 2013). Their multifunctional nature highlights the evolutionary significance of β -1,3-glucanases in both plant development and immunity.

Classification of β -1,3-Glucanase Gene Families

The extensive diversity of β -1,3-glucanases across plant species has long complicated their classification, as these enzymes are distributed across multiple clades within the glycoside hydrolase (GH) superfamily. Early classification attempts relied largely on parameters such as molecular size, sequence similarity, and isoelectric point, leading to the identification of several β -1,3-glucanase classes in species such as tobacco, barley, cotton, soybean, and rice. Despite their substantial structural similarity and conserved catalytic features, members within the same subgroup often display striking variations in spatial and temporal expression patterns, reflecting their functional specialization during plant development and stress responses (Perrot et al., 2022b).

Functionally, β -1,3-glucanases are broadly divided into endo- and exo-types, based on their hydrolytic mode of action. Endo- β -1,3-glucanases catalyze internal cleavage of β -1,3-D-glucosidic linkages, releasing oligosaccharides of variable lengths, whereas exo- β -1,3-glucanases sequentially trim glucose units from the terminal ends of glucan chains (Jiang et al., 2024b; Perrot et al., 2022b). These enzymatic types occur across several GH families, including GH16, GH17, GH55, GH64, GH81, GH128, and GH132. Structurally, endo- β -1,3-glucanases commonly exhibit a β -sheet-rich architecture composed of two antiparallel sheet layers, forming an extended catalytic cleft characteristic of the jelly-roll or sandwich fold (Jiang et al., 2024c). In contrast, plant-derived GH17 endo- β -1,3-glucanases frequently adopt a classical TIM-barrel fold, consisting of eight β -strands surrounded by eight α -helices, which supports substrate specificity and refined catalytic control. Exo- β -1,3-glucanases, especially those belonging to the GH55 family, predominantly originate from bacteria and fungi and are distinguished by two right-

handed parallel β -helix domains. Members of this group are highly efficient at degrading laminarin and interact with β -1,3-glucans found in fungal and plant cell walls (Jiang et al., 2024c).

Comprehensive phylogenetic and domain-architecture analyses have contributed substantially to the understanding of β -1,3-glucanase evolution. In *Arabidopsis thaliana*, 50 putative β -1,3-glucanase genes have been categorized into five major structural groups (Groups I–V), each defined by a distinct domain arrangement (Perrot et al., 2022b). All groups share two core features: an N-terminal signal peptide (NTS) and a conserved GH catalytic domain. Group V contains only these fundamental elements, whereas Groups I–IV possess additional modules. For example, Group II and Group IV proteins contain a carbohydrate-binding module (CBM43) or a hydrophobic C-terminal sequence (CTS), respectively. The CBM43 domain facilitates binding to β -1,3-glucans, while the CTS includes motifs resembling vacuolar targeting peptides or glycosylphosphatidylinositol (GPI)-anchor signals. Group I proteins combine both CBM43 and CTS domains, whereas Group III proteins possess two CBM43 domains but lack the CTS region.

Phylogenomic evidence indicates that the diversification of β -1,3-glucanases resulted from a series of gene duplication events followed by domain gain or loss and regulatory innovation. Ancestral Group I enzymes exhibit broad expression across tissues and are believed to contribute primarily to cell wall remodeling during growth and development. In contrast, stress-associated β -1,3-glucanases likely evolved through the acquisition of stress-responsive promoter elements and subsequent loss of the CTS region, enabling efficient extracellular secretion during pathogen attack. Consistently, *Arabidopsis* Group II, which lacks the CTS domain, is enriched in pathogenesis-related β -1,3-glucanases strongly induced upon fungal infection, suggesting a specialized function in degrading β -1,3-glucans within fungal cell walls (Perrot et al., 2022b). Collectively, the structural, functional, and phylogenetic classifications of β -1,3-glucanases highlight a dynamic evolutionary trajectory shaped by developmental requirements and biotic stress pressures.

Biochemical Functions of β -1,3-Glucanase in Plant Metabolism

β -1,3-Glucanases play multifaceted biochemical roles in plant metabolism, extending well beyond their established function in defense. These enzymes participate in essential physiological processes such as cell wall remodeling, cell division, reproductive development,

and symplastic connectivity (Kebede and Kebede, 2021a). One of their central substrates, callose, a β -1,3-glucan polymer, is dynamically deposited and degraded during critical developmental stages. For instance, callose functions as a permeability barrier surrounding pollen mother cells, regulating nutrient exchange and meiotic progression, and is similarly indispensable during muskmelon endosperm development where its controlled turnover ensures proper tissue differentiation. β -1,3-Glucanases mediate the timely degradation of callose in these processes, ensuring developmental transitions proceed normally (Islam et al., 2023). These enzymes are also key regulators of plasmodesmatal function, where they modulate callose deposition to control intercellular communication. By adjusting plasmodesmatal aperture, β -1,3-glucanases influence nutrient and signal transport and facilitate or restrict viral movement between cells, making them crucial components of both physiological signaling pathways and antiviral defense (Balasubramanian et al., 2012; De Storme and Geelen, 2014).

Biochemically, β -1,3-glucanases hydrolyze glucans containing contiguous β -1,3-linked glucose units. While they are primarily responsible for callose turnover in plants, they also degrade β -1,3- and β -1,3/1,6-glucans present in fungal cell walls, enabling plants to counteract invading pathogens (Perrot et al., 2022a). Their ability to cleave laminarin, a β -1,3-glucan with occasional β -1,6 branches found in brown algae, has resulted in their alternate designation as laminarinases. Substrates such as laminarin, paramylon, and pachyman are widely used to characterize their catalytic properties *in vitro* (Perrot et al., 2022a). This dual capability, management of endogenous callose metabolism and degradation of pathogen-derived glucans, underscores their critical importance in both plant growth regulation and immune responses. The precise hydrolytic mechanisms of β -1,3-glucanases contribute to the disruption of fungal cell wall integrity, thereby suppressing pathogen proliferation and mitigating disease progression (Kebede & Kebede, 2021b; Ahmed et al., 2020).

Role of β -1,3-Glucanase in Plant Immunity

β -1,3-Glucanases, classified as PR-2, are central components of plant immunity due to their ability to hydrolyze β -1,3-glucans, a major structural constituent of fungal cell walls. By degrading these polymers, β -1,3-glucanases directly suppress fungal growth, inhibit spore germination, and restrict pathogen invasion across diverse plant species (**Fig. 1**) (Perrot et al., 2022b). Numerous transgenic studies demonstrate that over-expression of β -1,3-glucanase genes in wheat, banana, tomato, and groundnut significantly enhances resistance to a wide range of

fungus pathogens, underscoring their potent antifungal activity both *in vitro* and *in planta*. The enzymatic degradation of fungal glucans not only compromises pathogen integrity but also generates β -1,3-glucan oligosaccharides that function as microbe-associated molecular patterns

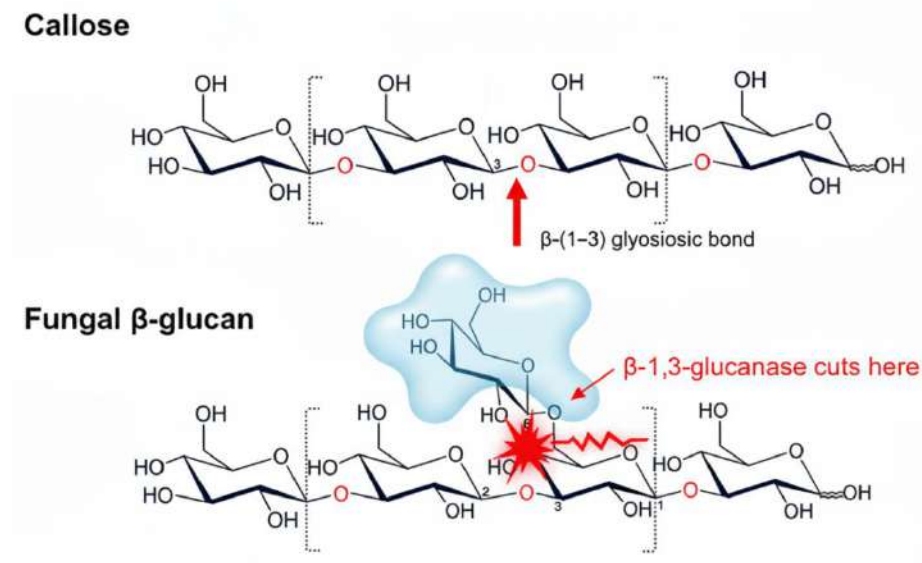


Fig. 1. β -1,3-glucanases catalyse the hydrolysis of glucans containing contiguous-1,3-linked glucosyl residues (Perrot et al., 2022).

(MAMPs). These MAMPs activate early immune signaling events, including pattern-recognition receptor (PRR)-mediated perception, mitogen-activated protein kinase (MAPK) signaling, and transcriptional reprogramming associated with systemic acquired resistance (SAR) (Fesel and Zuccaro, 2016; Van Boerdonk et al., 2024).

The elicitor-active glucan fragments released during hydrolysis also stimulate the accumulation of phytoalexins, reactive oxygen species (ROS), and the activation of salicylic acid (SA), jasmonic acid (JA), and abscisic acid (ABA)-regulated defense pathways (Jiang et al., 2024a; Riseh et al., 2023a). These responses collectively prime the plant for faster and stronger defense activation upon subsequent pathogen attack. Furthermore, β -1,3-glucanases regulate callose turnover at plasmodesmata, thereby modulating symplastic movement during immunity and developmental processes. Their involvement in callose degradation links them to diverse physiological pathways, including fruit development, pollen maturation, bud dormancy release, and stress adaptation, with loss-of-function mutants often displaying increased susceptibility or developmental defects (Perrot et al., 2022a).

Sulfated β -1,3-glucans, such as laminarin sulfate, have emerged as highly effective immune activators, inducing SA-dependent systemic resistance and antiviral responses. These compounds significantly reduce Tobacco Mosaic Virus lesion formation and stimulate strong PR gene expression in tobacco and Arabidopsis, illustrating the broad-spectrum signaling potential of β -glucan-derived elicitors (Riseh et al., 2023a). Despite their defensive importance, the role of β -1,3-glucanases is shaped by continuous co-evolution with pathogens. Several fungal species produce β -glucanase-inhibiting suppressor proteins, reflecting an evolutionary arms race between plant defenses and pathogen counter-defense strategies (Fesel and Zuccaro, 2016). **Table.1** list all the Functional studies of β -1,3-glucanase in plants.

Table 1. Functional Studies of β -1,3-Glucanase in Plants.

Plant / Organism	Gene / Source	Method / Strategy	Observed Effect on Immunity	References
Wheat (cv. Bobwhite)	Barley β -1,3-glucanase	Transgenic over-expression	Reduced Fusarium head blight severity; lower mycotoxin accumulation; fewer infected kernels	Bai et al., 2006
Wheat	β -1,3-glucanase + Chitinase	Co-over-expression (biolistic transformation)	Enhanced resistance to Fusarium; stronger antifungal effect than single gene	Shah et al., 2024
Eggplant	Alfalfa β -1,3-glucanase	Constitutive transgenic over-expression	Increased tolerance to Verticillium and Fusarium; broad antifungal activity	Islam et al., 2014
Groundnut, Potato, Banana, Flax	Various β -1,3-glucanases	Transgenic over-expression	Reduced lesion size, delayed disease progression, enhanced resistance in vitro and in planta	Riseh et al., 2023

Flax	Flax β -1,3-glucanase	Transgenic over-expression	Altered cell wall composition; lower callose; increased antioxidant potential; improved fungal resistance	Popelka et al., 2013
Strawberry (observational)	Fungal β -1,3-glucanase from <i>Trichoderma</i>	Constitutive expression	High glucanase activity enhanced resistance but caused stunted growth and reduced fruit yield	Li et al., 2015
Rice pathogen (<i>Magnaporthe oryzae</i>)	Exo- β -1,3-glucanase (<i>Ebg1</i>)	Fungal mutant / catalytically dead variant	Loss of enzymatic activity reduced virulence; pathogen unable to mask β -glucan MAMPs, highlighting plant-pathogen arms race	Liu et al., 2023

Signaling Pathways Mediated by β -1,3-Glucanase

β -1,3-Glucanases play a central role in plant immune signaling by hydrolyzing fungal β -glucans and generating oligosaccharides that serve as potent microbe-associated molecular patterns (MAMPs) (Fig. 2). Upon release, these β -glucan-derived elicitors are perceived by specific pattern recognition receptors (PRRs), initiating a rapid defense signaling cascade characterized by calcium influx, membrane depolarization, reactive oxygen species (ROS) bursts, nitric oxide production, and mitogen-activated protein kinase (MAPK) activation (Riseh et al., 2023a). The activation of MAPKs subsequently induces key transcription factor families, particularly WRKYs, which regulate the transcription of pathogenesis-related (PR) genes, including PR-1 and additional β -1,3-glucanase isoforms, thereby amplifying the defensive response (Riseh et al., 2023b). β -1,3-Glucanase-mediated signaling also integrates with major hormonal networks such as salicylic acid (SA), jasmonic acid (JA), and abscisic acid (ABA) which collectively determine the balance between salicylic-acid-dependent systemic acquired

The diagram illustrates the signaling pathways involved in the defense response of a plant cell against fungal pathogens. The process begins with the entry of fungal pathogens (Fungi) into the plant cell, which triggers the release of MAMPs (Microbe-Associated Molecular Patterns). These MAMPs are recognized by PRRs (Pattern Recognition Receptors) and Co-PRRs (Co-Pattern Recognition Receptors), leading to the activation of the Ca^{2+}/H^{+} ion fluxes. This activation is coupled with the NADPH oxidase enzyme, which converts O_2^- to H_2O_2 via the enzyme SOD (Superoxide Dismutase). The resulting H_2O_2 and the activation of the Ca^{2+}/H^{+} ion fluxes lead to the production of ROS (Reactive Oxygen Species) and a Nitric oxide burst. These events are part of the Early Defense Signals, which include immediate responses such as protein phosphorylation, lipid signaling, and an increase in cytosolic Ca^{2+} levels. These signals lead to the activation of the MAPK cascade, which in turn activates phytohormones (SA, JA/ET, and ISR). The activation of phytohormones leads to the activation of SAR (Systemic Acquired Response) and HR (Hypersensitive Response). SAR is associated with biotrophic fungi, while HR is associated with necrotrophic fungi. The activation of phytohormones also leads to the activation of NPR1/WRKY, which is involved in the signaling pathway leading to the activation of PR1, PR2, and PR3. The activation of these PRs leads to the strengthened cell wall (callose / β -1,3-glucan deposition), phytoalexin accumulation, and lignin biosynthesis, which are part of the local defense response.

Among β -glucan derivatives, sulfated β -1,3-glucans such as laminarin sulfate are particularly effective elicitors, strongly activating SA signaling through NPR1-dependent transcriptional activation of PR genes and conferring broad-spectrum resistance against fungal and viral pathogens in multiple species including tobacco and Arabidopsis (Riseh et al., 2023a). Notably, the efficiency of β -1,3-glucanase-triggered defense depends on the structural characteristics of the released oligosaccharides highlighting the specificity of receptor-mediated recognition across plant-pathogen systems (Fesel and Zuccaro, 2016). Collectively, β -1,3-glucanases function not only as hydrolytic enzymes but also as critical generators of immune elicitors, positioning them at the intersection of pathogen recognition, signal transduction, and transcriptional reprogramming that shapes the overall plant defense landscape (Fesel and Zuccaro, 2016).

Conclusion

β -1,3-Glucanases are essential enzymes that serve as both defenders and regulators in plants. They protect plants from fungal pathogens by breaking down β -1,3-glucans in fungal cell walls, weakening the invaders and limiting their growth. At the same time, the fragments produced act as signals that trigger the plant's immune system, preparing it for future attacks and enhancing overall disease resistance. In addition to their role in defense, β -1,3-glucanases contribute to fundamental plant processes, including cell wall remodeling, pollen development, seed germination, and fruit ripening, underscoring their importance in growth and development. Their activity is finely regulated by hormonal cues and environmental stresses, allowing plants to dynamically respond to changing conditions. Advances in understanding the regulation and function of β -1,3-glucanases offer promising avenues for crop improvement. Through targeted genetic approaches, such as over-expression or combined defense gene strategies, it is possible to enhance plant immunity, reduce disease-related losses, and minimize reliance on chemical pesticides, paving the way for more resilient and sustainable agriculture.

References

- Ahmed, A., Khatun, M., & Rahman, M. (2020). Roles of β -1,3-glucanases in plant defense and development. *Plant Pathology Journal*, 36(3), 203–215.
- Balasubramanian, V., Vashisht, D., Cletus, J., & Sakthivel, N. (2012). Plant β -1,3-glucanases: Their biological functions and transgenic expression against phytopathogenic fungi. *Biotechnology Letters*, 34(11), 1983–1990. <https://doi.org/10.1007/s10529-012-1012-6>.
- Bari, R., & Jones, J. D. G. (2009). Role of plant hormones in plant defence responses. *Plant Molecular Biology*, 69(4), 473–488. <https://doi.org/10.1007/s11103-008-9435-0>.
- Benitez-Alfonso, Y., Faulkner, C., Ritzenthaler, C., & Maule, A. J. (2013). Plasmodesmata: Gateways to local and systemic virus infection. *Molecular Plant-Microbe Interactions*, 26(1), 27–33. <https://doi.org/10.1094/MPMI-05-12-0129-IA>.
- Brown, G. D., & Gordon, S. (2005). Immune recognition of fungal β -glucans. *Cellular Microbiology*, 7(4), 471–479. <https://doi.org/10.1111/j.1462-5822.2005.00505.x>.
- Couto, D., & Zipfel, C. (2016). Regulation of pattern recognition receptor signalling in plants. *Nature Reviews Immunology*, 16(9), 537–552. <https://doi.org/10.1038/nri.2016.77>.

- De Storme, N., & Geelen, D. (2014). Callose homeostasis at plasmodesmata: Molecular regulators and developmental relevance. *Frontiers in Plant Science*, 5, 138. <https://doi.org/10.3389/fpls.2014.00138>.
- Dos Santos, C., & Franco, O. L. (2023). Pathogenesis-related proteins (PRs) with enzyme activity activating plant defense responses. *Plants*, 12(11), 2226. <https://doi.org/10.3390/plants12112226>.
- Fesel, P. H., & Zuccaro, A. (2016). β -glucan: Crucial component of fungal cell walls and elicitor of plant defense. *Molecular Plant Pathology*, 17(8), 1180–1185. <https://doi.org/10.1111/mpp.12350>.
- Fu, Z. Q., & Dong, X. (2013). Systemic acquired resistance: Turning local infection into global defense. *Annual Review of Plant Biology*, 64, 839–863. <https://doi.org/10.1146/annurev-arplant-042811-105606>.
- Islam, M. S., Lee, J., & Kim, J. H. (2023a). Callose dynamics during reproductive and seed development in muskmelon. *Plant Reproduction*, 36(1), 45–58. <https://doi.org/10.1007/s00497-022-00459-3>.
- Jiang, Y., Chang, Z., Xu, Y., Zhan, X., Wang, Y., & Gao, M. (2024a). Advances in molecular enzymology of β -1,3-glucanases: A comprehensive review. *International Journal of Biological Macromolecules*, 279, 135349. <https://doi.org/10.1016/j.ijbiomac.2024.135349>.
- Jiang, X., Wang, Y., Wang, X., et al. (2024b). Structural and functional diversification of β -1,3-glucanases in plants. *Plant Science*, 338, 111998. <https://doi.org/10.1016/j.plantsci.2023.111998>.
- Jiang, S., Chen, W., Li, Y., et al. (2024c). Structural diversity and catalytic mechanisms of β -1,3-glucanases across glycoside hydrolase families. *Carbohydrate Research*, 540, 109123. <https://doi.org/10.1016/j.carres.2023.109123>.
- Kebede, M., & Kebede, A. (2021a). β -1,3-glucanases: Biochemical functions, structure, and role in plant immunity. *Journal of Plant Biochemistry and Biotechnology*, 30(4), 559–572. <https://doi.org/10.1007/s13562-021-00704-1>.
- Kebede, A., & Kebede, M. (2021b). In silico analysis of promoter region and regulatory elements of glucan endo-1,3-beta-glucosidase encoding genes in *Solanum tuberosum*:

- Cultivar DM 1-3 516 R44. *Journal of Genetic Engineering and Biotechnology*, 19(1), 145. <https://doi.org/10.1186/s43141-021-00240-0>
- Kriznik, M., et al. (2017). Grapevine responses to fungal pathogens: A focus on PR proteins. *Plant Physiology and Biochemistry*, 115, 273–284. <https://doi.org/10.1016/j.plaphy.2017.03.020>
- Lagaert, S., Beliën, T., & Volckaert, G. (2014). Plant cell walls: Protecting the barrier from degradation by microbial enzymes. *Critical Reviews in Microbiology*, 40(4), 351–370. <https://doi.org/10.3109/1040841X.2013.813902>
- Levy, A., Erlanger, M., Rosenthal, M., & Epel, B. L. (2007). A plasmodesmata-associated β -1,3-glucanase in *Arabidopsis*. *The Plant Journal*, 49(4), 669–682. <https://doi.org/10.1111/j.1365-313X.2006.02985.x>
- Miedes, E., Vanholme, R., Boerjan, W., & Molina, A. (2019). The role of the secondary cell wall in plant resistance to pathogens. *Frontiers in Plant Science*, 10, 973. <https://doi.org/10.3389/fpls.2019.00973>
- Perrot, T., Pauly, M., & Ramírez, V. (2022a). Emerging roles of β -glucanases in plant development and adaptive responses. *Plants*, 11(9), 1119. <https://doi.org/10.3390/plants11091119>
- Perrot, T., Zhou, M., Kieffer, E., et al. (2022b). Evolutionary diversification of plant β -1,3-glucanases and their roles in development and immunity. *Plant Physiology*, 189(4), 2380–2396. <https://doi.org/10.1093/plphys/kiac447>
- Riseh, R. S., Vazvani, M. G., & Kennedy, J. F. (2023a). β -glucan-induced disease resistance in plants: A review. *International Journal of Biological Macromolecules*, 253, 127043. <https://doi.org/10.1016/j.ijbiomac.2023.127043>
- Riseh, R. S., Kim, J. S., & Lee, Y. H. (2023b). β -glucans as potent elicitors of plant immunity: Mechanisms and applications. *Frontiers in Plant Science*, 14, 1165442. <https://doi.org/10.3389/fpls.2023.1165442>
- Sels, J., Mathys, J., De Coninck, B. M., et al. (2008). Plant immune responses triggered by microbial molecules. *Trends in Plant Science*, 13(7), 233–239. <https://doi.org/10.1016/j.tplants.2008.03.004>
- Van Boerdonk, S., Saake, P., Wanke, A., Neumann, U., & Zuccaro, A. (2024a). β -Glucan-binding proteins are key modulators of immunity and symbiosis in mutualistic plant–

- microbe interactions. *Current Opinion in Plant Biology*, 81, 102610.
<https://doi.org/10.1016/j.pbi.2024.102610>
- Van Loon, L. C., Geraats, B. P. J., & Linthorst, H. J. M. (2006). Ethylene as a modulator of disease resistance in plants. *Trends in Plant Science*, 11(4), 184–191.
<https://doi.org/10.1016/j.tplants.2006.02.005>
- Velásquez-Zapata, V., Gómez-Merino, F. C., & Trejo-Téllez, L. I. (2023). Pathogenesis-related proteins in plant immunity: Recent advances and biotechnological applications. *Journal of Plant Physiology*, 286, 154012. <https://doi.org/10.1016/j.jplph.2023.154012>
- Vetvicka, V., & Vetvickova, J. (2020). Variation in β -glucan composition from yeast, fungi, algae, and cereals and its influence on biological activity. *Nutrients*, 12(6), 1553.
<https://doi.org/10.3390/nu12061553>
- Yang, Y., Wang, Q., Chen, Q., & Huang, Q. (2018a). Functional roles of β -1,3-glucanases in plants. *Plant Signaling & Behavior*, 13(1), e1425676.
<https://doi.org/10.1080/15592324.2017.1425676>
- Yu, X., Feng, B., He, P., & Shan, L. (2022). From pathogen perception to the activation of plant immune responses: A molecular perspective. *The Plant Cell*, 34(4), 1556–1584.
<https://doi.org/10.1093/plcell/koac021>

Volume: 05 Issue No: 12

CLIMATE-SMART IRRIGATION IN COFFEE PLANTATION

Article ID: AG-VO5-I12-06**Abinesh. R.V*, Chandana. M, Kishore Mote and Babou. C**

Division of Agronomy, Central Coffee Research Institute, Balehonnuru, Karnataka, India

*Corresponding Author Email ID: rv.abinesh2000@gmail.com

Introduction

Climate-smart irrigation refer to sustainable and adaptive approaches in agricultural water management that consider the impact of climate change. These practices aim to enhance water use efficiency, minimize environmental impact and promote resilience to climate-related challenges.

Why Smart Irrigation for Coffee?

Coffee is a water-sensitive crop that requires specific moisture levels for optimal growth. Too little or too much water can negatively affect bean quality, flowering and yield. Smart irrigation ensures:

- Consistent soil moisture
- Efficient water use
- Improved bean development
- Climate-resilient farming practices

Principles of Climate-smart irrigation

1. **Climate change adaptation** - Involving adjustments to irrigation practices, improved water use efficiency and the implementation of technologies for resilience to climate challenges in agriculture.
2. **Climate change mitigation** - Focusing on enhancing water use efficiency, minimizing greenhouse gas emissions and adapting methods to changing climatic conditions.
3. **Enhancing crop and water productivity** - Emphasizing achieving higher crop yields with less water consumption through optimized irrigation for greater agricultural

productivity while adapting to changing climate conditions.

4. **Minimizing environmental impact** - Climate-smart irrigation aim to reduce water pollution and other environmental hazards associated with irrigation, such as over-extraction of groundwater or excessive use of fertilizers.
5. **Maximizing water use efficiency** - This involves using irrigation techniques that deliver water precisely where it's needed, such as drip irrigation or micro-sprinklers, minimizing water loss through evaporation or runoff

Micro irrigation

- Sprinkler irrigation
- Drip irrigation

Sprinkler irrigation

Advanced pressured micro-irrigation method mirroring natural rainfall. This technique involves the distribution of irrigation water over the crop canopy through an aluminum or high-density polyethylene (HDPE) pipe system. The adoption of sprinkler systems for cereals and other field crops has yielded substantial irrigation water savings ranging from 30% to 70%. The advantages encompass improved water distribution efficiency, reduced water waste and enhanced agricultural sustainability. The broader implementation of sprinkler irrigation stands poised to contribute significantly to resource efficient and sustainable agricultural practices globally, addressing water conservation challenges and promoting optimal crop growth.



Drip irrigation

Drip irrigation is an effective technique for delivering irrigation water directly to the root zone of plants, thereby reducing conventional losses such as deep percolation, runoff and soil erosion, particularly in water-scarce regions with undulating topography, shallow soils and widely spaced high-value crops like coffee (Babou *et al.*, 2017).



Additionally, it allows possible to use irrigation water along with fertilizer's, insecticides and other water-soluble chemicals, which increases yields and improves produce quality. The main types of drip irrigation are

- a. Surface drip irrigation
- b. Subsurface drip irrigation

a. Surface drip irrigation

Surface drip irrigation stands as a sophisticated, low-volume technique meticulously delivering irrigation water (IW) directly to plant roots near the soil surface. Operating through a meticulously designed network of pipes, valves and emitters, this system not only ensures efficient water and nutrient transport but also minimizes soil erosion risks. A notable feature of surface drip irrigation is its incorporation of fertigation, a process where fertilizers are seamlessly integrated with irrigation water, curbing nutrient loss through leaching. Surface drip irrigation systems, demonstrating savings of up to 50% in cereals like wheat, rice, maize, and various other crops.

b. Sub-Surface Drip Irrigation (SSDI)

SSDI emerges as an innovative system that distinguishes itself from surface drip irrigation by minimizing labor costs associated with anchoring laterals during the cropping season, concurrently ensuring the longevity of these laterals. This method not only addresses practical concerns but also delivers substantial benefits in terms of water conservation, nutrient application efficiency, weed control and overall agricultural management. The fundamental principle - reducing water loss from the soil surface due to evaporation. streamlines cultural operations. By facilitating the direct application of water and nutrients to the crop root zone, SSDI optimizes fertilizer use, curtails weed growth, lowers labor costs and streamlines cultural operations costs. The broader adoption of SSDI holds immense promise for sustainable agriculture, aligning with global efforts to address water scarcity and promote resource-efficient practices. By mitigating water loss, enhancing nutrient utilization and minimizing labor inputs, SSDI, especially when integrated with CA practices, emerges as a transformative approach with the potential to revolutionize irrigation strategies and contribute significantly to resilient and sustainable food production systems.

Automation in Micro-irrigation

Automated drip irrigation systems revolutionize traditional agricultural practices, offering

precise and efficient water management. Utilizing technology to monitor soil moisture, climate conditions and soil types, these systems enable accurate field irrigation. Sensors, microcontrollers and wireless communication enhance the automation, allowing real-time data analysis for optimized water utilization. Drip irrigation, in particular, delivers water directly to plant roots, minimizing wastage and conserving resources. This innovation addresses water and manpower limitations, providing intelligent, sensor-based solutions for increased yield per drop, reduced water consumption and improved overall agricultural productivity

Sensors

Precision irrigation relies on real-time data, requiring sensors to monitor soil moisture, temperature and meteorological conditions. Initially, tensiometers and granular matrix sensors were used for soil moisture estimation, later replaced by electromagnetic based sensors, showing promise for real-time monitoring. The collected data, converted from analog to digital by microcontrollers, is transmitted using RF modules, Bluetooth or Wi Fi to a base station. Automation involves irrigation controllers activating solenoid valves based on predefined soil moisture thresholds. Wireless sensor networks (WSNs) enhance automation, exemplified by a drip irrigation system with various sensors like soil moisture, wind speed and direction sensors, providing increased spatial and sequential resolutions. Some systems utilize tensiometers to detect soil metric potential for irrigation scheduling, integrating automated controllers. Recent advancements, like use of RF modules for remote monitoring and comprehensive analyses, highlight the role of wireless sensor networks and information and communication technologies in advancing precision agriculture technology.

Wireless sensor networks (WSNs)

Wireless Sensor Networks (WSNs) have emerged as a valuable tool for precision agriculture, providing real-time data to enhance productivity and efficiency while mitigating risks associated with climatic anomalies, water shortages and pests. Microcontroller advancements and wireless communication technologies, such as Zigbee, Wi-Fi, Bluetooth, RF and General Packet Radio Service (GPRS), contribute to the development of low-power, low-cost components essential for WSNs.

Internet of Things (IoT)

In smart irrigation system **Internet of Things (IoT)** refers to a system of **connected devices and sensors** (such as soil moisture sensors, water pumps and weather monitors) that

collect, transmit and analyze real-time data to enable **automated and efficient irrigation management**. Through IoT connectivity, farmers can monitor soil moisture status via a mobile application or web page, providing information on water sprinkler status. The model includes a sensor hub and a control hub, offering valuable insights for multi-cropping systems. This technology reduces manual efforts for irrigation, improving efficiency and production, particularly beneficial in rural areas with limited rainfall. An IoT-based irrigation monitoring and control system employing various sensors and actuators. This smart irrigation system autonomously delivers an appropriate amount of water from a reservoir to crops, demonstrating the potential for efficient and automated irrigation management. The system aimed to enhance agricultural productivity by enabling autonomous monitoring and operation of a remote farm.



Utilizing a soil moisture sensor, a pump and a Wi-Fi module, the system collected and transmitted real-time data to a web server. This allowed users to monitor soil moisture levels, ensuring precise irrigation control. The system's flexibility and cost-effectiveness were supported by experimental and simulation results, emphasizing the benefits of remote monitoring and control for irrigation supplies.

1. Soil moisture sensors

Soil moisture sensors are essential tools for monitoring and managing soil water content, playing a pivotal role in agriculture, environmental science, and landscaping. They utilize different principles like resistance, capacitance, and electromagnetic wave propagation to measure soil moisture content. Choosing the right type of sensor depends on factors like accuracy, cost, and sensitivity to environmental conditions.

Working Principles:

- a. **Resistive Sensors:** These sensors measure the electrical resistance of the soil. As soil moisture increases, the conductivity and the ability of the soil to conduct electricity also increase, resulting in a decrease in resistance.

- b. Capacitive Sensors:** These sensors measure the capacitance between two metal plates (forming a capacitor) with the soil as the dielectric medium. The dielectric constant of the soil changes with moisture content, which in turn affects the capacitance.
- c. TDR (Time Domain Reflectance) Sensors:** TDR sensors send a short pulse of electromagnetic energy through a coaxial cable buried in the soil. The speed and strength of the reflected pulse are affected by the soil's moisture content, allowing the sensor to calculate the water content.
- d. FDR (Frequency Domain Reflectance) Sensors:** FDR sensors transmit and receive electromagnetic waves through the soil. The speed of these waves is affected by the moisture content, and the sensor measures the frequency changes to determine the water level.

2. Evapotranspiration controllers

Evapotranspiration (ET) controllers are advanced irrigation systems that adjust watering schedules based on the combined processes of plant transpiration and soil evaporation. By aligning irrigation with actual plant water needs, these controllers optimize water usage, reduce waste and promote healthier landscapes. ET controllers calculate the amount of water plants require by estimating evapotranspiration rates. They adjust irrigation schedules accordingly, considering factors like temperature, humidity, wind speed and solar radiation.

There are several types of ET controllers:

- 2.1** Standalone controllers that determine climatic variables from on-site sensors and then measure ET.
- 2.2** Signal-based controllers that collect ET data and rain information via wireless communication from weather stations (satellite signals).
- 2.3** Historical-based controllers that rely on monthly historical ET information for the area.

3. Rain sensors

A rain sensor is an electronic device that senses rainwater and triggers a response in a connected system such as stopping irrigation, to conserve water and improve operational efficiency. A rain sensor is a device that detects the presence or amount of rainfall. It manages water usage in agriculture, landscaping or gardening and adjust irrigation schedules accordingly. This improves water efficiency, reduces waste and supports sustainable



farming or landscaping practices. RS can delay or interrupt the scheduled irrigation cycle when there is a predetermined amount of rain that disables the solenoid valves until the sensor dries out. Typically, RS should be installed in open areas where they will be exposed to unobstructed rainfall. By using RS, runoff or deep percolation can be minimized, weed pressure and diseases can be reduced, and unnecessary irrigation events can be eliminated.

4. Optical sensors

The above-mentioned sensors used for precision irrigation require particular hardware for wired and wireless connections to buried sensors, which may lose signal due to disconnection issues. To avoid using SMS buried in the soil, novel techniques have been applied to manage irrigation by using optical sensors such as drones, UAV and red/green/blue (RGB) cameras. UAV-based remote sensing is a breakthrough technology that has been extensively exploited in smart irrigation over a large scale due to its cost-effectiveness, easy construction procedures, convenient transportation, high flexibility, short operating cycle and relatively high resolution.

References

- Babou, C., Rudragouda, D.S. Mukharib, Kishor Mote, Nagaraj Gokavi, Ramya, Manjunath, A.N. and Raghuramulu, Y. (2017). Influence of micro irrigation and drip fertigation practices on yield and quality parameters of robusta coffee (*Coffea canephora*). *Int.J.Curr.Microbiol.App.Sci* . 6(2): 701-706
- Hareesh, S. B., Shivaprasad, P., Greeshma, G., Sushmitha, N., and JS, N. Smart Monitoring of Soil Chemical Properties in Coffee Plantation through IoT (Internet of Things) Sensor.
- Kumar, S., Yadav, A., Kumar, A., Hasanain, M., Shankar, K., Karan, S., and Dayal, P. (2023). Climate smart irrigation practices for improving water productivity in India: a comprehensive review. *International Journal of Environment and Climate Change*, 13(12), 333-348.
- Martello, M., Molin, J. P., Bazame, H. C., Tavares, T. R., and Maldaner, L. F. (2022). Use of active sensors in coffee cultivation for monitoring crop yield. *Agronomy*, 12(9), 2118.
- Touil, S., Richa, A., Fizir, M., Argente Garcia, J. E., and Skarmeta Gomez, A. F. (2022). A review on smart irrigation management strategies and their effect on water savings and crop yield. *Irrigation and Drainage*, 71(5), 1396-1416.

DEFOLIATOR PESTS OF ONION: IDENTIFICATION AND CONTROL MEASURES

Article ID: AG-VO5-I12-07

V. Karuppaiah*, and Soumia P.S

ICAR-Directorate of Onion and Garlic Research, Pune, Maharashtra-410505, India

*Corresponding Author Email ID: karuppaiahv2008@gmail.com

Introduction

Onion (*Allium cepa* L.) is an important member of the family Amaryllidaceae (formerly Alliaceae) and is a widely grown herbaceous biennial vegetable crop. Insect pests and diseases are the major constraints affecting onion production and productivity. Among the various insect pests damaging onion, leaf-feeding defoliators such as the beet armyworm (*Spodoptera exigua* Hubner) (Lepidoptera: Noctuidae), tobacco caterpillar (*Spodoptera litura* Fabricius) (Lepidoptera: Noctuidae), black cutworm (*Agrotis ipisilon* Hufnagel) (Lepidoptera: Noctuidae), Green loopers (*Chrysodeixis acuta* Walker) (Lepidoptera: Noctuidae), and head borer (*Helicoverpa armigera* Hubner) (Lepidoptera: Noctuidae) are the important defoliators species infesting onion in India.

Being polyphagous in nature, these pests can cause significant damage under favourable conditions. The beet armyworm alone is capable of causing up to 34% damage, with losses ranging from 70.0% to 81.9% recorded in some popular *rabi* onion varieties. Similarly, the black cutworm can destroy entire fields under severe attack, especially during the early crop stages. Although these pests are often regarded as minor, occasional, or sporadic in onions, their potential to become devastating under favourable climatic conditions should not be underestimated.

In view of these facts, this article summarizes the description of major defoliator pests, their damage symptoms, and the management strategies suggested by various studies to aid onion growers in effectively and economically combating these pests.

Common cutworm, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae)

Pest description and identification: The young caterpillars are light green with black head or black dots, and they are seen in cluster. Pupae are pale yellow to brown in colour and pupate in the soil. Adults are slender, yellowish brown, and approximately 1 mm in long, brown in colour. The forewings are brown with wavy white patterns, possess reniform spot is brown outlined with a white margin and has a marking of letter “A” at the apex area, orbicular spot is elongate, narrow, oblique, light brown and outlined with a white margin. Hind wings are white with a brown patch along the edges. Creamy white eggs are laid in masses, and covered with silky hairs.

Symptom of damage: The larva is the damaging stage. Larvae can be found in nursery beds and newly transplanted onion fields. They feed gregariously on the foliage, scraping the leaf surface and giving it a papery appearance.



Fig 1. *S. liura* larvae and damaged leaf

Beet army worm, *Spodoptera exigua* Hubner (Lepidoptera: Noctuidae)

Pest description and identification: The early instar larvae are pale green in colour, turning into greyish in colour with black head. Older larvae have broad striped pattern on both sides and are usually dark green or grayish black in colour. Pupae are light brown in colour and pupate in the soil. Adults are medium- sized, with mottled grey and brown forewings; the orbicular spot is round and light or yellowish brown with a white margin surrounded by a thin black margin. Whereas, the hind wings are uniform grey or or white. White eggs are laid in clusters towards the apex of the leaves and covered with scales

Symptom of damage: The larva is the damaging stage. The larvae feed gregariously during the initial days, particularly on the growing tips of onion leaves, by scraping the mesophyll layer. As they mature, they become solitary and continue feeding on the tubular leaves, creating irregular

holes. In the advanced stages, the larvae capable of making bore small tunnels and feed on the outer layers of the bulb, resulting in superficial damage that is externally visible. They also attack the umbel and flower stalks in seed crops. Severe infestations cause extensive defoliation, and heavily infested fields appear as white, papery patches when viewed from a distance.



Fig 2. *S. exigua* damage



Fig 3. *S. exigua* larvae

Green looper, *Chrysodeixis acuta* Walker (Lepidoptera: Noctuidae)

Pest description and identification: Larvae are glossy green and have three pairs of abdominal legs (prolegs); forms a characteristic loop or hump while crawling (semi-loop). Pupa is green at first and then turns brown; also forms a white silken cocoon. Adult moths are brown; forewings bear a dark brown pattern with two distinctive silver spots and have tiny silver spots along the median region. Hind wings are also brown. The eggs are yellowish- white and deposited singly on the leaf surface.

Symptom of damage: The larva is the damaging stage. The larvae feed on onion leaves; the early instars scrape the leaf surface, making it translucent and revealing the caterpillars inside the hollow, tubular leaves. The later instars produce feeding cuts and cause more extensive leaf damage.



Fig 4. *C. acuta* larva



Fig 5. *C. acuta* damage in onion

Black cutworm, *Agrotis ipsilon* (Lepidoptera: Noctuidae)

Pest description and identification: The larvae are light grey to black in colour and have greasy look. Pupae are brown, spindle shaped; formed inside a soil puparium. Adult moths have dark gray colouration with dagger-shaped pattern on the forewing. When disturbed the larva coils up into 'C' shape. *A. ipsilon* is a localized pest in areas where sugarcane, maize, potato and other related crops are grown.

Symptom of damage: The larva is the damaging stage. The larvae usually hide in cracks and crevices in the soil during the daytime. They feed on the tender foliage of young seedlings, and the later instars cut the stalks completely at the ground level. Onion fields irrigated through drip systems are more prone to infestation due to the presence of loose, moist soil conditions that favour larval activity. The damage often occurs in patches, but under severe infestation, entire fields may be destroyed.



Fig 6. *Agrotis* damage in onion

Head borer, *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae)

Pest description and identification: The colour of the larva varies from greenish to brown. Green with dark brown grey lines laterally side of the body, and lateral white lines with dark and pale bands. Fully-grown larva is greenish with dark brown grey lines along the side of body and measures about 35-45 mm in length. Pupa is brown in colour, occurs in soil, within stalk and crop debris. The adult is light pale brownish yellow stout moth. Fore wing grey to pale brown with "V" shaped speck. The hind wings are pale smoky white with a broad blackish outer margin. The eggs are spherical in shape, creamy white in colour and laid singly.

Symptom of damage: The larva is the damaging stage. The head borer is primarily a pest of onion seed crops and occurs sporadically in fields grown for seed production. The larvae cut the pedicels of the flowers and feed on the stalks. A single larva can damage multiple flower stalks. The infestation results in defoliation, breaking of umbel stalks, and poor or malformed umbel formation, ultimately reducing seed yield.



Fig 7. *H. armigera* larva



Fig 8. *H. armigera* damaged umbel

Management strategies: Pheromone traps for *Agrotis ipsilon*, *Spodoptera litura* and *Helicoverpa armigera* @ 4-5 traps /acre. The traps should be fixed to supporting poles at a height of about one foot above the plant canopy. Lures should be replaced regularly at 2-3 week intervals. Light traps (1 trap/acre), placed about 15 cm above the crop canopy, can also be used for monitoring and mass trapping of adult moths. Bio-pesticides, *Bacillus thuringiensis* (Bt) formulations @ 1 kg/ha and neem seed kernel extract (NSKE) 5% have been found promising against *Spodoptera exigua* on onion.

For *Spodoptera* species, application of chlorantraniliprole 18.5% SC @ 0.15 ml/l and spinosad 45% SC @ 0.12 ml/l is effective. Spinetoram 12% SC, applied @0.8 ml/l will significantly minimize leaf damage and enhances bulb yield. Cyantraniliprole 10% OD @ 0.9 ml/l can be effectively used against cutworms and green loopers.

Flood irrigation is recommended immediately after noticing *A. ipsilon* infestation, as it helps to reduce larval populations in the soil. Spraying chlorpyrifos @ 1 l/ha or neem-based formulations @ 3% is also suggested for managing cutworms.

Conclusion

The cutworm, green looper, and head borer are the prominent defoliator pests of onion in India. Although their frequency of occurrence is generally low, they can cause severe damage under favourable climatic conditions. Regular monitoring of these polyphagous pests, along with awareness of their biology, damage symptoms, and management strategies, is crucial for effective pest diagnosis and control. This article provides an overview of the key defoliator pests of onion, their nature of damage, and available options for effective and economical management to assist onion growers and researchers in mitigating their impact.

References

- Rao D. V. S and Subbaratnam G V. (1999). Seasonal incidence and population dynamics of *Spodoptera exigua* (Hubner) in onion. *Pest Management and Economic Zoology*, 7: 39-45.
- Karuppaiah, V., Soumia, P.S, Thangasamy, A. and Mahajan, V. 2016. Incidence of black cutworm *Agrotis ipsilon* in Rabi onion. *DOGR News*, 20(2):6-7.
- Karuppaiah, V., Soumia, P. S. and Major Singh. 2019. Occurrence of green semi-looper, *Chrysodeixis acuta* Walker in onion (*Allium cepa* L) (Amaryllidaceae). *Florida Entomologist*, 102(4): 783.
- Soumia P.S, Karuppaiah V., Mahajan V. and Singh M. (2020). Beet armyworm, *Spodoptera exigua*: Emerging threat to onion production. *National Academy Science Letters*: doi.org/10.1007/s40009-020-00892-5
- Soumia, P.S., Karuppaiah, V and Singh, M. (2017). Managing *Thrips tabaci* - a pest of national significance. *Indian Horticulture*, 62(6): 55-56.
- Sreenivas, A.G., Sushila N., R Shankaramurthy, V., Raghavendra Y., Rani S., Patil, N., Ashrith, K. N. and Vinay S. Patted. (2016). Eco-friendly approaches for the management of defoliators on onion. *Progressive Horticulture*, 48(2). DOI : 10.5958/2249-5258.2016.00033.6
- Srinivas, P.S., Singh. R.P. and Lawande, K.E. (2007). Integrated Pest and Disease Management in Onion and Garlic. Technical Bulletin No.17. ICAR-Directorate of Onion and Garlic Research, Pune, Maharashtra, pp.34.
- Satyagopal, K., et al. (2014). AESA based IPM package for onion. Department of Agriculture and cooperation, Ministry of Agriculture, Government of India. P 60.

Volume: 05 Issue No: 12

DIAGNOSIS AND CONTROL OF GASTROINTESTINAL PARASITES IN SMALL RUMINANTS

Article ID: AG-VO5-I12-08**L. Arun¹ and C. Inbaraj²**¹Assistant Professor, Department of Veterinary Animal Husbandry Extension,²Assistant Professor, Department of Veterinary Medicine, Veterinary College and Research
Institute, Tamilnadu Veterinary and Animal Sciences University (TANUVAS)

Udumalpet – 642 205, Tamil Nadu, India

*Corresponding Author Email ID: vetinba@gmail.com

Introduction

The presence of nematode eggs or tapeworm segments during a stool examination might be used to confirm GI parasite infection. Examining faeces can be further divided into qualitative and quantitative assessments. To prevent environmental contamination by free-living stages of nematodes, faeces should be fresh, and samples should ideally be taken before they come into contact with the ground. Faeces should be taken straight from the rectum if an individual animal is thought to be ill.

Qualitative Faecal Evaluation

A centrifugation faecal flotation performed on individual animal feces or on composite samples from multiple animals within a herd enables a qualitative assessment of the types of GI nematodes shedding eggs in the feces and a subjective assessment of the magnitude of infection. Composite fecal sampling is a robust method for evaluating parasite burden within a herd that is a resource-efficient option for owners and producers.

Faecal samples must be refrigerated in an airtight container and used within five days to prevent the development of parasite eggs. A number of flotation solutions have been approved for use with the excrement of ruminants. Parasite eggs rise to the top if their specific gravity is lower than that of the flotation solution. After being retrieved, these parasites are placed on a glass plate for microscopic inspection. If an egg is denser than the selected solution and does not float, this could result in false negatives.

Several commercially available sugar and salt flotation solutions are validated for use in ruminants. Each flotation solution has a different specific gravity (and therefore different recovery of specific parasites) and a different shelf life.

Although sugar solutions have a shorter shelf life than salt solutions and can be susceptible to bacterial or fungal development unless a preservative is added, they do not alter egg morphology and can be studied after a few hours or days if chilled. Although salt solutions have a longer shelf life, slides must be viewed right away after preparation since crystallisation will damage or destroy parasite egg membranes.

Most common GI nematode eggs will be recovered if a flotation solution has a specific gravity of at least 1.24 (Sheather's sugar flotation solution has a specific gravity of 1.26–1.27). Passive flotation is no longer an acceptable **standard of practice**.

Quantitative Fecal Evaluation:

Several fecal egg-counting techniques have been validated for use in ruminants and have different levels of sensitivity. Examples of techniques include modified Stoll's, modified McMaster's, Wisconsin, FEKPAK (Australia), and mini-FLOTAC. Fecal egg counts are a more objective measure of the number of parasite eggs than is fecal flotation, and they can indicate the efficacy of dewormers (discussed in Treatment). Fecal egg counts can provide robust information about herd health, and with good record keeping they can create a strong clinical picture of infection patterns within herds over time. Veterinarians and owners can use these patterns to establish treatment thresholds.

The relative fecundity of female worms, which varies depending on the nematode genus; the presence of immature nematode stages that are not yet producing eggs but are still causing damage to GI tract mucous membranes; diarrhoea (dilution of eggs); and the recent use of dewormers are some of the factors that affect the number of eggs in a sample. Furthermore, some egg-counting methods fail to identify the genus or species of trichostrongyle-type eggs and require specialised equipment. For these reasons, treatment and management of clinical GI parasitism should not be based only on faecal egg counts.

Postmortem Examination

All animals suspected to have died as a result of GI parasitism should undergo a postmortem examination. Each section of the GI tract should be examined for mucosal defects, hemorrhages, erosions or ulcers, and the presence of nematodes or cestodes attached to the

mucosa. These parasites can be very small and threadlike, and each species has a preference for a particular GI tract section.

GI contents can be collected and run through screens to identify parasite larvae or adults. Larvae and adults can be identified to the level of genus with microscopy by specialty labs; molecular techniques make identification of the species possible. Histopathology should be conducted on abnormal sections of the GI tract to identify parasites embedded in the mucosal wall.

Blood work

Anaemia and hypoproteinemia, which is typified by hypoalbuminemia, are significant bloodwork abnormalities in ruminants clinically impacted by GI parasites. Although the total blood count differential may show eosinophilia, clinical parasitism cannot be ruled out by a benign result. Electrolyte abnormalities, such as hyponatraemia, hypochloremia, hypokalaemia, and metabolic acidosis marked by bicarbonate loss, may be present in animals with severe, acute infections that cause diarrhoea.

In animals with abomasal parasitism, abomasal pH may increase as acid production decreases secondary to parietal cell damage. Samples may be obtained by abomasocentesis. Pepsinogen, the inactive form of pepsin, is not activated if the abomasum is not acidic. Increased concentrations of serum pepsinogen may be found in cases of severe type II ostertagiasis; however, few diagnostic laboratories in the US offer this test anymore.

Prevention and control of Parasite in ruminants:

Infection with GI parasites does not equate to disease; in fact, animals that are not exposed to a low load of GI parasites will never form protective immunity and are more at risk of severe disease when exposed. For this reason, preventive measures should center on preventing disease rather than eliminating all parasites.

A preventative program can address each of the three components of epidemiology—host, environment, and pathogen. proper nutrition, particularly protein, proper vitamin and mineral supplementation, if necessary to boost the immune system, avoidance of common disorders that cause immunosuppression, and avoidance of stress are host variables that help prevent clinical GI parasitism. Paying particular attention to bunk space, crowding, social group mixing, and typical stresses like weaning, vaccinations, shearing, etc. are examples of host variables.

Resistance to GI parasitism and immune response to GI parasite challenges are heritable traits that have been studied extensively in sheep. Recommended methods include breeding animals that seem resistant to GI parasite burdens, and culling poor doers from a breeding program.

The free-living stages of GI parasites on pasture, and the effect of environmental management on parasite epidemiology, make pasture management a critical tool for effective prevention of disease. Susceptible animals (young animals without acquired immunity, pregnant animals, sick animals, etc) should not be exposed to pastures that are potentially highly contaminated with parasites. Exploiting the typical life cycle and characteristics of GI nematodes can aid in effective pasture management. Here are some examples:

- Trichostrongyles speed up their life cycle and increase their population under ideal environmental conditions.
- Intervention: Remove grazing animals from pasture after rain events, or during humid and mild conditions.
- Infectious L3s can vertically migrate only short distances and are found close to the ground.

Intervention: Graze only pastures with forage longer than 10 cm.

- Production animals do not share pathogenic GI nematodes with other nonruminant species and can help clear pastures of parasites for each other.
- Intervention: Co-graze or alternately graze high-risk pastures with different species (eg, horses).
- Drug-resistant parasites survive treatment with certain drugs and may be the only population left after deworming, contaminating a “clean” pasture.
- Intervention: Avoid deworming the entire herd at one time, and do not move the animals to clean pasture immediately after deworming.
- Trichostrongyles require pasture and cannot complete their life cycle when exposed to high heat, desiccation, or prolonged direct sunlight.
- Intervention: House animals on concrete or dry lots during high-risk periods or in cases of severe multidrug resistance.
- Trichostrongyle L3s have a finite lifespan that depends on environmental conditions.

Treatment of Gastrointestinal Nematodes

Owners should be made aware of the possibility that administering anthelmintics to extremely ill animals could result in their death. Because underdosing can quickly result in anthelmintic resistance and overdose may have negative effects on the animal's health or cost the owner money, careful anthelmintic dosing should be based on precise weights for each individual animal.

GI nematodes have been shown to be resistant to all medication classes, particularly in the Southeast. Because of this, posttreatment diagnostics and confirmation that clinical indications have subsided should be used to closely monitor anthelmintic efficacy. Since rotational deworming has been shown to continue the development of antibiotic resistance, it is no longer advised. On farms with known resistance, combination deworming—the simultaneous administration of two or three medications from different drug classes—may be utilised. Since they have similar mechanisms of action, additional medications in the same class should be avoided when data suggests that a farm is resistant to a specific medication.

The benzimidazole drug class includes albendazole, fenbendazole, oxfendazole, and thiabendazole. These drugs have variable activity against inhibited larvae, such as *Ostertagia*.

Fenbendazole has a wide margin of safety, and its doses and frequency of administration can be increased above the label amount in many cases (veterinarians must follow laws, requirements, and restrictions for extra-label drug use). Studies on fenbendazole have shown an increased killing capacity with multiple-day dosing because the efficacy of this dewormer increases with increased length of drug exposure.

Albendazole, on the other hand, has a little safety margin and cannot be safely raised in either frequency or dose. Albendazole overdose causes teratogenesis, pancytopenia, and bone marrow suppression. Benzimidazoles may be more effective when animals are fasted before receiving them since this decreases the GI transit time and increases the parasite's exposure to the anthelmintic. Benzimidazole resistance is not unusual, and even if the medication is not used on a farm for a number of years, susceptibility cannot be restored once resistance has arisen.

Levamisole is an imidazothiazole drug and has a narrow therapeutic index because it targets acetylcholine receptors and can affect those of the host as well as the parasite; however, it is water soluble and easy to administer. Levamisole has very little activity against inhibited larvae. Morantel and pyrantel are tetrahydropyrimidines and have a wider margin of safety than

levamisole. Morantel is a feed additive and, like other any anthelmintic delivered in feed, may not be administered in an effective dose if the animal does not consume the entire amount. Underdosing may result and, eventually, lead to anthelmintic resistance.

Signs of toxicosis from imidazothiazole or tetrahydropyrimidine drugs include typical “SLUD” clinical signs—salivation, lacrimation, urination, and defecation—in addition to hyperexcitability, trembling, ataxia, collapse, and death from respiratory failure.

The macrocyclic lactone drug class includes the drugs ivermectin, doramectin, moxidectin, and eprinomectin. These drugs are highly effective against adult, larval, and inhibited larval stages.

Macrocyclic lactones were affordable, extremely effective, and capable of controlling both internal and external parasites when they were initially brought to the commercial market. Since their introduction, GI nematodes all over the world have developed resistance to the macrocyclic lactones because of their extensive use in suppressive deworming efforts. Pour-on formulations may have prolonged activity, which would reduce labour costs for application; but, because concentrations decrease with time, parasites may be exposed to sublethal dosages, which could accelerate the development of anthelmintic resistance.

All drugs are available in a variety of forms (oral, injectable, and pour-on) to suit all types of management systems. Outside of the US, several additional drugs are available in each drug class, including combination deworming products. Some narrow-spectrum anthelmintics, such as the salicylanilide closantel, have excellent activity against *Haemonchus contortus* in sheep and remain in the host for a long time. Haloxon, an organophosphate, is approved for use against GI nematodes in calves.

Combination Anthelmintic Treatment

Administering full doses of two or three classes of dewormers simultaneously can improve efficacy through an additive effect that resembles the concept of broad-spectrum antibiotic coverage. In addition to management changes, this deworming approach can be useful in herds with documented multidrug resistance and limited deworming options. Because fewer resistant GI nematodes survive and a larger refugium provides greater dilution of the resistant gene pool, combination deworming can even slow the development of multidrug resistance. Meat or milk withdrawal times should be based on the drug that has the longest withdrawal interval.

Anthelmintic-related Diagnostic Techniques

The increase of severe, widespread multidrug resistance has necessitated the monitoring of drug efficacy. Drug resistance should be suspected when other factors, such as improper dosage, poor nutrition, rapid reinfection, or disease other than GI parasites, are excluded. The fecal egg count reduction test (FECRT) is the primary means of assessing drug efficacy within a herd.

According to the local epidemiology of parasites in the area, the FECRT should be carried out in individual herds every two to three years during the season when egg counts are anticipated to be at their peak. For this test, 10–15 younger animals with higher expected egg counts or FAMACHA scores should ideally be selected. To account for variations in egg counts unrelated to a medication therapy, an **untreated** control group can be utilised. Because individuals can significantly skew the egg counts in small groups, data from an FECRT should be interpreted cautiously for very small flocks or herds.

Fecal egg counts (FECs) are conducted on the same day that an anthelmintic is administered; then a second fecal egg count is made on the same individual between 10 and 14 days after application of the treatment. The time period between the pretreatment and posttreatment samples is critical to avoid confounding with reinfection by a separate parasite population. The fecal egg count reduction (FECR) can be calculated as follows: $\%FECR = ([\text{pretreatment FEC} - \text{posttreatment FEC}] / \text{pretreatment FEC}) \times 100$.

Alternate drugs:

A wide variety of nondrug control measures exist for ruminants and can be used in an adjunctive manner as part of an integrated parasite management plan. Approaches to pasture management include resting pastures to allow for the natural attrition of infectious L3 larvae, managing forage height, and allowing mixed-species grazing.

High amounts of dietary protein enhance the ability of ruminants to resist clinical parasitism and support the immune response to parasite challenge. The administration of copper oxide wire particles as a bolus has been shown to decrease the *Haemonchus contortus* worm burden in sheep and goats; however, care must be taken to avoid copper toxicity in these sensitive species. The addition of condensed tannin forages and predacious, nematode-trapping fungi (*Duddingtonia flagrans*) in feed has also been shown to decrease worm burden and fecal egg counts in treated animals; however, these substances need to be fed continuously.

IMPORTANCE OF SOIL ORGANIC CARBON FOR SOIL FERTILITY AND CROP PRODUCTIVITY

Article ID: AG-VO5-I12-09***¹A. Premalatha, ²S. Saravanakumar and ³Dr.N. Bommayasamy**¹Scientist (Soil Science), ²Scientist (Agronomy) KVK MYRADA, Erode District, TN³Senior Scientist & Head, ICAR KVK - North Goa, India

*Corresponding Author Email ID: apremalatha93@gmail.com

Introduction

Soil organic carbon (SOC) is one of the most important indicators of soil health and productivity. It represents the carbon component of soil organic matter derived from plant residues, animal wastes, root exudates, and microbial biomass. Soil organic carbon influences soil physical, chemical, and biological properties, thereby determining the capacity of soil to support healthy plant growth. However, due to intensive cultivation, excessive tillage, removal or burning of crop residues, and imbalanced fertilizer use, SOC levels in many Indian soils have drastically declined. Most cultivated soils in India contain less than 0.5% organic carbon, far below the optimum level required for sustaining high agricultural productivity. Declining SOC not only reduces soil fertility but also affects water retention, nutrient availability, microbial activity, and overall crop performance. Enhancing soil organic carbon has gained significant attention worldwide, not only for improving crop production but also for mitigating climate change through carbon sequestration.

Soil Organic Carbon Components and Fractions

Soil organic carbon is composed of different fractions that vary in their stability and function. Labile carbon is the easily decomposable fraction consisting of simple sugars, amino acids, microbial biomass, and fresh plant residues. It provides immediate energy to soil microorganisms and plays a major role in nutrient mineralization. However, it is rapidly lost through decomposition, especially in tropical climates and under intensive tillage. The slow carbon fraction consists of partially decomposed organic matter such as humic substances, which

contribute to soil structure formation and nutrient retention. The stable or passive carbon fraction includes resistant compounds like lignin and humus that decompose very slowly and are responsible for long-term carbon storage and soil resilience. Maintaining a balance between labile and stable carbon is essential for ensuring both immediate nutrient availability and long-term soil fertility. The distribution of these fractions determines the sustainability of soil productivity and its capacity to withstand climatic and management stresses.

Soil Carbon Dynamics and Microbial Role

Soil organic carbon undergoes continuous cycling through decomposition, mineralization, humification, and stabilization processes. Microorganisms play a central role in these transformations. Bacteria and fungi break down organic residues into simpler compounds, releasing nutrients in plant-available forms. Fungal hyphae contribute to soil aggregation, while actinomycetes decompose complex polymers such as cellulose and lignin. Root exudates serve as carbon sources for microbes, stimulating microbial activity in the rhizosphere. This microbial hotspot enhances nutrient turnover, increases soil enzyme activities, and improves nutrient uptake by plants. Mycorrhizal fungi form symbiotic relationships with plant roots, improving phosphorus and micronutrient absorption while contributing to carbon storage in soil aggregates. The dynamic interaction between soil organic carbon and microbial communities determines the efficiency of nutrient cycling and soil biological health. A decline in SOC results in reduced microbial diversity and activity, leading to lower nutrient availability and weakened soil functioning.

Carbon-to-Nitrogen Ratio and Nutrient Availability

The carbon-to-nitrogen (C:N) ratio of organic inputs plays a major role in determining the rate of decomposition and nutrient release. Organic materials with a low C:N ratio, such as green manures and leguminous biomass, decompose rapidly and release nitrogen for plant use. In contrast, materials with a high C:N ratio, such as straw and sugarcane trash, decompose slowly and may temporarily immobilize nitrogen, making it unavailable to crops. An ideal C:N ratio of soil organic matter is around 10–12:1, which optimizes microbial activity and nutrient mineralization. Proper management of organic residues ensures that carbon additions do not cause nutrient deficiencies. Balancing carbon and nitrogen inputs is essential for maintaining efficient nutrient cycling and achieving sustained soil fertility.

SOC and Soil Physical Properties

Soil organic carbon plays a major role in improving soil physical properties. It binds soil particles together to form stable aggregates, which reduce erosion, increase porosity, and improve aeration. Improved aggregation enhances root penetration and supports better plant growth. Higher SOC increases the soil's water-holding capacity, particularly in sandy soils where moisture retention is limited. Research indicates that even a small increase in SOC can significantly enhance soil water storage, which is crucial under drought conditions. SOC also reduces soil bulk density, making the soil easier to till and less prone to compaction. Improved physical properties result in better seed germination, root development, and overall plant performance.

SOC and Soil Chemical Properties

SOC influences several chemical properties of soil. It enhances nutrient availability by increasing cation exchange capacity, allowing soil to hold and release essential nutrients such as calcium, magnesium, potassium, and micronutrients. SOC also chelates micronutrients, preventing their fixation and making them available to plants. It buffers soil pH, reducing the harmful effects of soil acidity or alkalinity on nutrient uptake. Soils rich in SOC retain nutrients for longer periods and release them gradually, reducing losses through leaching and volatilization. Higher SOC improves fertilizer-use efficiency, enabling farmers to achieve better crop yields with lower external input costs. ★ ★ ★ ★ ★

SOC and Soil Biological Properties

Soil organic carbon serves as the primary energy source for soil organisms. Higher SOC levels support increased microbial biomass, enhanced enzyme activities, and improved biological nitrogen fixation. SOC promotes earthworm activity, which enhances soil structure and fertility through casting and burrowing. Earthworms increase nutrient availability by fragmenting organic residues and enhancing microbial decomposition. The biological processes supported by SOC contribute to nutrient cycling, disease suppression, and soil regeneration. A decline in SOC leads to reduced biological activity, making soils more dependent on external fertilizers.

Impact on Crop Productivity

Soil organic carbon significantly influences crop productivity. It improves water availability, nutrient supply, soil structure, and microbial interactions, all of which contribute to better plant growth. Soils with higher SOC show higher yields, improved crop quality, and

greater resilience to drought and temperature stress. SOC-rich soils maintain productivity even under reduced fertilizer application, making them ideal for low-input farming systems. Improved soil structure and moisture retention support better germination and root development, resulting in healthier crops. SOC is therefore essential for achieving stable and sustainable crop production.

Carbon Sequestration and Climate Resilience

Increasing soil organic carbon contributes to carbon sequestration by storing atmospheric carbon dioxide in the soil. This process helps mitigate climate change while improving soil health. SOC enhances climate resilience by improving drought tolerance, reducing erosion, stabilizing soil temperatures, and increasing water-use efficiency. These benefits are especially important in rainfed and climate-sensitive agricultural systems. Soils with higher SOC act as carbon sinks and play a crucial role in environmental sustainability.

Management Practices to Improve SOC

Several agricultural practices can enhance soil organic carbon levels. Incorporating crop residues instead of burning them adds organic matter to the soil. Green manuring with leguminous crops supplies both carbon and nitrogen. Application of farmyard manure, compost, and other organic amendments increases soil organic matter content. Reduced tillage minimizes carbon losses through oxidation. Cover cropping and mulching protect soil from erosion and provide continuous organic inputs. Agroforestry systems increase biomass production and contribute to long-term carbon storage. Sustainable soil management focuses on increasing carbon inputs while minimizing carbon losses, thereby improving soil fertility and productivity.

Conclusion

Soil organic carbon is a fundamental component of soil fertility and crop productivity. It influences soil physical, chemical, and biological properties, enhancing water retention, nutrient availability, and microbial activity. Increasing SOC improves soil structure, supports resilient crop production, and contributes to climate change mitigation through carbon sequestration. By adopting carbon-building practices, farmers can improve crop yields, reduce dependency on chemical fertilizers, and promote environmental sustainability.

FOOD NANOSENSORS: FOOD SAFETY AND QUALITY MANAGEMENT

Article ID: AG-VO5-I12-10**Amuthaselvi.G***

Department of Food Process Engineering, Agricultural Engineering College & Research Institute, Tamil Nadu Agricultural University, Coimbatore-3, Tamil Nadu, India

*Corresponding Author Email ID: g.amuthaselvi@gmail.com

Introduction

Ensuring food safety and quality remains one of the most critical challenges of the 21st-century food industry. With increasing globalization of food supply chains, consumers face heightened risks of exposure to foodborne pathogens, chemical contaminants, adulterants, allergens, and spoilage-related hazards. Conventional analytical methods—including chromatography, ELISA, PCR, and mass spectrometry—are accurate but limited by high cost, labor intensiveness, long processing time, and the need for specialized laboratories. In contrast, nanosensor technologies offer rapid, sensitive, portable, and real-time detection platforms capable of continuous monitoring across the entire food chain.

The emergence of nanotechnology in food science has enabled the design of sensors at the scale of atoms and molecules, dramatically increasing the surface-to-volume ratio and enhancing reactivity, specificity, and signal sensitivity. Food nanosensors can identify contaminants in trace concentrations (ppb to ppt), respond instantly to environmental changes, and be embedded into packaging or processing systems for non-destructive, continuous surveillance. Such capabilities make nanosensors ideal tools for the early detection of microbial spoilage, mycotoxins, pesticide residues, allergens, and chemical hazards.

Moreover, advancements in Internet of Things (IoT), wireless communication, and AI-driven data processing have further strengthened the potential of nanosensors to support smart food manufacturing and blockchain-based traceability systems. Nanosensors are now integral in developing intelligent packaging that visually alerts consumers about product freshness,

embedded markers for temperature and humidity control, and nano-enabled biosensors for rapid diagnostics in field conditions.

This review explores the principles, materials, fabrication techniques, classifications, and industrial applications of food nanosensors. It also examines regulatory concerns, toxicological considerations, commercialization barriers, and future directions to establish a comprehensive understanding of the role of nanotechnology in modern food safety and quality management.

2. Fundamentals of Nanotechnology and Nanosensing

2.1 Definition and Scope of Nanotechnology

Nanotechnology involves the manipulation of materials at dimensions between 1 and 100 nm. At this scale, materials exhibit unique physical, chemical, electrical, optical, and biological properties that differ from their bulk counterparts. These properties enable faster reactions, enhanced sensitivity, and unique surface interactions essential for sensor development.

2.2 Nanosensing: Concept and Mechanism

Nanosensing refers to the detection of chemical or biological analytes using nanoscale materials or structures. The sensing mechanism typically involves:

- **Adsorption** of analytes onto the nanomaterial
- **Change in surface energy** or electronic structure
- **Transduction** of this change into a measurable signal (optical, electrical, mechanical, thermal)

The ultra-high surface area of nanoparticles facilitates increased interaction with analytes, enabling detection at extremely low concentrations.

3. Types of Nanomaterials Used in Food Nanosensors

Nanomaterials used in food nanosensing are selected based on stability, reactivity, biocompatibility, and functionalization capability. Key nanomaterials include:

3.1 Metal Nanoparticles

- **Gold nanoparticles (AuNPs):** Widely used in colorimetric sensors
- **Silver nanoparticles (AgNPs):** Antimicrobial + sensing dual role
- **Metal oxides (ZnO, TiO₂, Fe₃O₄):** Used in electrochemical sensors

3.2 Carbon-Based Nanomaterials

- **Carbon nanotubes (CNTs):** Excellent electrical conductivity
- **Graphene and graphene oxide:** High surface area, ideal for electrochemical sensors

- **Fullerenes:** Antioxidant and photothermal sensing applications

3.3 Quantum Dots (QDs)

- Semiconductor nanoparticles with strong fluorescence
- Used for allergen and toxin detection

3.4 Magnetic Nanoparticles

- Enable magnetic separation of pathogens, enhancing detection sensitivity

3.5 Polymeric Nanomaterials

- Chitosan, polyaniline, PLA-based nanostructures for biodegradable sensors

Each nanomaterial provides distinct advantages depending on the sensing methodology and target analyte.

4. Classification of Food Nanosensors

Food nanosensors can be categorized based on the type of detection mechanism:

4.1 Optical Nanosensors

Optical nanosensors rely on visible or invisible light signals in response to analyte binding. Optical nanosensors represent one of the most powerful and widely used categories of nanosensing systems in the food industry due to their high sensitivity, rapid response, and ability to detect chemical and biological contaminants through light-based signals. These sensors operate by monitoring changes in optical properties such as color, fluorescence, absorbance, scattering, refractive index, or Raman signals when a target analyte interacts with a nanomaterial. At the nanoscale, materials like gold nanoparticles, silver nanoparticles, carbon dots, quantum dots, and graphene exhibit unique optical behaviors—especially surface plasmon resonance (SPR) and fluorescence—making them ideal for detecting even trace amounts of contaminants. When an analyte binds to or alters the environment around these nanomaterials, it produces a measurable optical change, which can often be detected visually or through simple optical devices, enabling fast and non-destructive analysis.

One of the most common types of optical nanosensors is the colorimetric nanosensor, which typically uses gold or silver nanoparticles. These nanoparticles display distinct colors depending on their dispersion or aggregation states. For instance, when gold nanoparticles aggregate in the presence of certain pesticides, toxins, or metal ions, the solution visibly changes from red to blue. This simple, naked-eye detection capability makes colorimetric nanosensors popular for field analysis and rapid screening of contaminants such as pesticide residues, heavy

metals like mercury and lead, adulterants, and microbial toxins. Fluorescent nanosensors, on the other hand, rely on nanomaterials that emit light upon excitation. Quantum dots, carbon dots, and dye-tagged nanoparticles produce strong fluorescence signals that change in intensity or wavelength when interacting with analytes. These sensors are widely used for detecting allergens, aflatoxins, antibiotic residues, pathogenic DNA, and other trace-level contaminants with exceptional sensitivity.

Another important class of optical nanosensors is SPR and LSPR-based sensors. These sensors measure changes in refractive index near the nanomaterial surface when an analyte binds to it. Thin gold films, gold nanorods, and plasmonic nanoparticles are typically used for SPR sensing. They allow real-time, label-free detection of proteins, pathogens, toxins, adulterants, and food allergens. Localized SPR (LSPR) sensors, which rely on the oscillation of electrons on nanoparticle surfaces, offer even greater sensitivity due to their high electromagnetic field confinement. LSPR sensors are especially effective for detecting volatile organic compounds (VOCs), amines, and gases associated with food spoilage.

Surface-enhanced Raman scattering (SERS) nanosensors form another advanced category, capable of amplifying Raman signals by several orders of magnitude using roughened silver or gold nanostructures. Because every molecule generates a unique Raman fingerprint, SERS is ideal for identifying pesticides, food dyes, chemical adulterants, and pathogens with extraordinary accuracy and speed. Similarly, photoluminescent and photonic crystal-based nanosensors can detect changes in gas composition, pH, humidity, and spoilage markers in real time, making them suitable for intelligent packaging applications. Overall, optical nanosensors provide rapid, non-invasive, and highly selective detection solutions for a wide range of food safety concerns, enabling improved quality monitoring, extended shelf life assessment, and real-time spoilage detection throughout the food supply chain. Their ability to integrate with smartphones, portable detection devices, and smart packaging systems positions them as essential tools in the future of food safety and precision food monitoring.

4.1.1 Colorimetric Sensors

Colorimetric nanosensors are one of the simplest, fastest, and most visually interpretable types of optical nanosensors used in food safety and quality monitoring. These sensors rely on **distinct color changes** that occur when nanoparticles—most commonly **gold nanoparticles (AuNPs)** or **silver nanoparticles (AgNPs)**—interact with specific analytes and undergo

aggregation or dispersion. At the nanoscale, gold and silver particles exhibit unique optical properties governed by **localized surface plasmon resonance (LSPR)**, meaning their color is strongly influenced by particle size, shape, and interparticle spacing. When a target contaminant such as a pesticide, heavy metal ion, toxin, or adulterant binds to functionalized nanoparticles, it alters their aggregation state, causing a visible shift in color. For example, dispersed AuNPs often appear red, but when they aggregate due to the presence of analytes like mercury ions, melamine, or certain pesticides, the solution changes to blue or purple. This simple, naked-eye detection capability makes colorimetric nanosensors extremely attractive for rapid, on-site testing without requiring advanced instruments or trained personnel.

In the food industry, colorimetric nanosensors have found wide application because they offer high sensitivity, low cost, and portability. They are used to detect **pesticide residues** on fruits and vegetables, **heavy metals** such as Pb^{2+} and Hg^{2+} in water and beverages, **mycotoxins** like aflatoxin in grains, and **microbial contamination** through bacterial metabolites or cell surface markers. These sensors also play a significant role in identifying **food adulteration**, such as urea in milk, artificial dyes in spices, and synthetic chemicals in edible oils. Many colorimetric nanosensors are designed to operate in “turn-on” or “turn-off” modes, where the color becomes more intense or fades depending on the concentration of the target analyte. Some recent advancements include using polymer-coated nanoparticles, enzyme-assisted reactions, and DNA/aptamer-functionalized nanomaterials to increase selectivity and lower detection limits. Additionally, integrating smartphone cameras with image-processing apps enables quantitative color analysis, making these sensors more precise and user-friendly. Overall, colorimetric nanosensors offer a powerful, low-cost, and rapid means of detecting a wide range of contaminants, making them an essential tool in modern food safety monitoring and smart packaging applications.

- Visible color change due to aggregation of AuNPs
- Used for:
 - Pesticides
 - Heavy metals
 - Microbial toxins

4.1.2 Fluorescent Sensors

Fluorescent nanosensors are a highly sensitive class of optical sensors that detect

contaminants in food by measuring changes in fluorescence intensity, wavelength, or emission patterns when specific analytes interact with nanoscale fluorescent materials. These sensors commonly use **quantum dots (QDs)**, **carbon dots (CDs)**, **graphene quantum dots (GQDs)**, **upconversion nanoparticles (UCNPs)**, or fluorescent dye-tagged nanomaterials, all of which exhibit strong, stable, and tunable fluorescence. The fundamental principle behind fluorescent nanosensing is that when a target analyte binds to or influences the surface of these nanomaterials, it affects their fluorescence through mechanisms such as **fluorescence quenching, enhancement, electron transfer, or Förster resonance energy transfer (FRET)**. These molecular-level interactions enable the detection of extremely low concentrations—often at parts per billion or even parts per trillion—making fluorescent nanosensors ideal for identifying hazardous contaminants that pose significant health risks.

In food safety and quality control, fluorescent nanosensors have become essential because they offer rapid, real-time, and highly selective detection of a wide range of analytes. They are widely used to identify **mycotoxins** such as aflatoxin B1 and ochratoxin A, **antibiotic residues** like tetracyclines and chloramphenicol, **food allergens** including peanut and milk proteins, and **pathogenic bacteria** by targeting their DNA, proteins, or metabolic markers. For example, quantum dot-based biosensors can detect *Salmonella* DNA by exhibiting a notable reduction in fluorescence when hybridization occurs, while carbon dot sensors change their fluorescence in the presence of metal ions or pesticide molecules. These sensors are particularly valuable for liquid foods, dairy products, meat, and beverages, where transparent matrices allow efficient optical detection.

Advancements in fluorescent nanosensor technology have also paved the way for portable and user-friendly platforms. Smartphone-based fluorescence readers, microfluidic chips, and paper-based fluorescence strips allow field-level testing without the need for laboratory equipment. Furthermore, fluorescent nanosensors can be integrated into intelligent packaging to monitor freshness by detecting spoilage indicators such as biogenic amines, organic acids, and pH changes. Their exceptional sensitivity, fast response time, and adaptability make fluorescent nanosensors one of the most promising tools for next-generation food safety monitoring; however, challenges related to nanoparticle toxicity, environmental stability, and standardized validation must still be addressed to enable widespread commercial adoption.

- Quantum dots or dye-tagged nanoparticles

- Detect allergens, proteins, aflatoxins

4.1.3 Surface Plasmon Resonance (SPR) Sensors

Surface plasmon resonance (SPR) nanosensors are highly advanced optical sensors that detect contaminants based on changes in the refractive index occurring at the surface of a plasmonic metal—typically **gold or silver**. SPR is a phenomenon in which free electrons on a metal surface oscillate collectively when excited by incident light at a specific angle or wavelength. When analytes such as proteins, toxins, pathogens, or chemical contaminants bind to the functionalized metal surface, they alter the local refractive index, causing a measurable shift in the SPR signal. This shift is directly correlated to the analyte concentration, allowing **real-time, label-free, and highly sensitive detection** without the need for chemical dyes or secondary tagging agents. Because SPR **monitors** molecular binding events as they occur, it is particularly useful for studying biomolecular interactions in food matrices with exceptional precision.

In the food industry, SPR sensors are increasingly used for detecting **pathogenic bacteria** like *Salmonella*, *E. coli*, and *Listeria* by capturing specific antigens or DNA sequences on the sensor surface. They are also effective for analyzing **food allergens**, including gluten and peanut proteins, which pose severe health risks for sensitive individuals. Beyond biological contaminants, SPR sensors can detect **chemical hazards** such as pesticide residues, veterinary drug residues, adulterants, and toxins like aflatoxin and ochratoxin. Their ability to provide direct, quantitative measurement makes them valuable for monitoring milk adulteration, verifying meat authenticity, and ensuring product purity in beverages, oils, and processed foods. Recent advancements, such as integrating nanoparticles, nanorods, and graphene with SPR platforms, have significantly enhanced sensitivity, enabling the detection of extremely low analyte concentrations.

SPR sensors are also gaining importance in smart food packaging and production line monitoring. Miniaturized SPR chips, portable SPR devices, and coupling with smartphones or IoT systems provide continuous and automated detection capabilities suitable for real-time quality control. Despite their many advantages, some limitations remain—SPR systems may be expensive, require precise calibration, and can be affected by complex food matrices with high viscosity or turbidity. Nonetheless, with ongoing improvements in nanofabrication and surface chemistry, SPR nanosensors represent a powerful and rapidly evolving technology that holds

strong potential for ensuring food safety and authenticity across global supply chains.

4.2 Electrochemical Nanosensors

Electrochemical sensors measure current, voltage, impedance, or conductivity changes due to analyte interaction. Electrochemical nanosensors are highly sensitive analytical devices that detect chemical and biological contaminants in food by measuring electrical signals—such as current, voltage, or impedance—generated during interactions between analytes and nanostructured electrodes. These sensors commonly use **nanomaterials like carbon nanotubes (CNTs), graphene, gold nanoparticles, silver nanoparticles, metal–organic frameworks (MOFs), and nanocomposites**, which significantly enhance electron transfer and increase the active surface area for sensing. When a target molecule binds to the functionalized electrode surface, it induces a measurable **electrochemical change** through mechanisms such as **redox reactions, conductivity changes, catalytic activity, or charge transfer**, allowing rapid, real-time detection even at extremely low concentrations. Because of their ability to directly convert chemical interactions into electrical signals, electrochemical nanosensors are valued for their high sensitivity, low detection limits, portability, and compatibility with compact, battery-powered devices.

In the food industry, electrochemical nanosensors have become indispensable tools for detecting **pesticide residues, heavy metals, mycotoxins, antibiotics, adulterants, allergens, and spoilage indicators**. For example, CNT- or graphene-modified electrodes enable precise detection of lead, cadmium, and mercury in water and beverages, while gold nanoparticle-based biosensors can identify aflatoxin B1, chloramphenicol, or *E. coli* DNA within minutes. Enzyme-linked electrochemical sensors are used to measure glucose, lactose, and other nutritional components, whereas aptamer- and antibody-coated nanostructured electrodes provide high selectivity for pathogens and allergens. Electrochemical nanosensors are also widely used for monitoring **food freshness**, as they can detect biogenic amines and other spoilage metabolites released during the deterioration of fish, meat, and dairy products.

Recent advancements include the development of **wearable and flexible electrochemical sensors, screen-printed electrodes (SPEs)** for field testing, and integration with **smartphone readout systems**, making these sensors practical for on-site or consumer-level applications. Paper-based electrochemical nanosensors have further improved affordability and sustainability, enabling rapid, disposable testing devices suitable for routine quality checks.

Despite these advantages, electrochemical nanosensors may be affected by complex food matrices, electrode fouling, and the need for careful calibration. However, with advancements in nanomaterial engineering and sensor miniaturization, electrochemical nanosensors continue to emerge as one of the most reliable, sensitive, and promising tools for modern food safety monitoring and quality assurance.

4.3 Mechanical Nanosensors

Mechanical nanosensors represent an emerging yet powerful class of detection tools in food safety and quality monitoring, relying on nanoscale mechanical transduction principles to detect target analytes through changes in mass, force, pressure, or deformation. These sensors typically operate using nanomechanical structures such as cantilevers, nanowires, graphene membranes, or quartz crystal microbalances (QCM), each of which exhibits exceptionally high sensitivity due to their small size, large surface area-to-volume ratio, and low mechanical stiffness. When analytes such as pathogens, toxins, gases, adulterants, or spoilage metabolites bind to the functionalized surface of a nanomechanical element, they induce minute changes in resonance frequency, deflection, or vibration amplitude. These mechanical alterations are then converted into quantifiable signals. For example, micro- and nanocantilevers coated with selective receptors bend measurably when target molecules adsorb to their surface, allowing label-free, real-time detection down to picomolar or even single-molecule levels. Similarly, QCM-based nanosensors detect extremely small mass changes by monitoring shifts in oscillation frequency, making them highly suitable for monitoring volatile organic compounds (VOCs), freshness indicators, and pathogen-derived molecules in food systems. Carbon nanotube and graphene-based mechanical sensors have gained increasing attention because of their exceptional elasticity, electrical conductivity, and high mechanical strength, enabling ultralow detection limits for contaminants such as heavy metals, allergens, and pesticide residues.

A major advantage of mechanical nanosensors is their ability to perform non-destructive, real-time monitoring without requiring labeling or complex chemical reactions. Their high stability and compatibility with microfluidic platforms allow integration into portable and point-of-need devices suitable for food supply chains. Recent work has also explored flexible and wearable mechanical nanosensors that can be attached to packaging films to track freshness indicators like ammonia, biogenic amines, and microbial metabolites through dynamic mass loading and swelling-induced deformation. Despite their promising capabilities, several

challenges still hinder their widespread application in food monitoring. Issues such as signal drift, susceptibility to environmental fluctuations (temperature, humidity, and vibration), and the need for robust surface functionalization remain areas of active research. Additionally, translating nanoscale mechanical signals into reliable, standardized outputs for industrial use requires sophisticated readout systems and advanced data processing. Nevertheless, ongoing advancements in nanofabrication, hybrid materials, and machine learning–assisted signal interpretation are rapidly enhancing their performance. As these innovations mature, mechanical nanosensors are expected to play a central role in next-generation smart packaging, automated quality control, and continuous monitoring systems across the food production and distribution chain.

Nano-cantilever systems detect mass changes caused by analyte binding.

- Sensitivity in femtogram range
- Useful for detecting pathogens and proteins

4.4 Biological (Bio-Nano) Sensors

Biological (bio-nano) sensors represent one of the most advanced and versatile categories of nanosensors for food safety and quality assessment, integrating biological recognition elements with nanomaterials to achieve highly selective, sensitive, and rapid detection of contaminants. These sensors rely on bioreceptors such as enzymes, antibodies, aptamers, peptides, nucleic acids, phages, and even whole cells, which are immobilized onto nanoscale transducers made from materials like gold nanoparticles, carbon nanotubes, graphene, magnetic nanoparticles, or quantum dots. When the bioreceptor interacts specifically with its target—such as pathogenic bacteria, toxins, allergens, pesticide residues, mycotoxins, or foodborne viruses—the binding event triggers a measurable change in optical, electrical, or mechanical properties of the underlying nanomaterial. This synergy between biological specificity and nanomaterial-enhanced signal amplification enables extremely low detection limits, often down to femtomolar or single-cell levels, making bio-nano sensors ideal for early detection of food contamination.

A key strength of biological nanosensors is their ability to provide high selectivity due to the precise recognition mechanisms inherent in biological molecules. Aptamer-based nanosensors, for example, bind to targets with affinity comparable to antibodies, while offering advantages such as thermal stability, easy synthesis, and the ability to detect small-molecule contaminants. Enzyme-based nanosensors convert target interactions into chemical reactions,

producing clear and quantifiable signals that are useful for detecting freshness indicators like glucose, histamine, or ethanol produced during spoilage. Phage-based nanosensors have emerged as powerful tools for pathogen detection because bacteriophages naturally recognize specific bacteria; when combined with nanomaterials like magnetic nanoparticles or fluorescent tags, they enable rapid and selective detection even in complex food matrices. The incorporation of nanomaterials significantly enhances these biological interactions by increasing surface area, improving immobilization efficiency, and boosting the overall sensitivity through plasmonic, catalytic, or electrical amplification.

Despite their advantages, bio-nano sensors face several challenges that must be addressed before large-scale adoption in the food industry. Biological components can be sensitive to environmental factors such as temperature, pH, and long-term storage conditions, potentially reducing sensor stability. Efforts to overcome these limitations include the use of synthetic bioreceptors (e.g., aptamers and molecularly imprinted polymers), improved immobilization techniques, and protective nanocoatings. Scalability and cost-effectiveness also remain concerns, particularly for sensors designed for disposable packaging applications. Nonetheless, advancements in biotechnology, nanofabrication, and microfluidics—combined with AI-driven signal interpretation—are rapidly improving the robustness and practicality of bio-nano sensors. As these technologies continue to evolve, biological nanosensors are expected to play a transformative role in real-time contamination monitoring, smart packaging, automated quality control systems, and next-generation food safety surveillance across global supply chains.

4.5 Gas Nanosensors

Gas nanosensors are a rapidly expanding category of nanotechnology-based sensing systems designed to detect gaseous compounds associated with food spoilage, contamination, and quality changes with exceptionally high sensitivity and fast response times. These sensors typically employ nanostructured materials—such as metal oxide nanoparticles (ZnO , TiO_2 , SnO_2), carbon nanotubes, graphene, quantum dots, or noble metal nanoclusters—as the active sensing elements because their extremely high surface area and tunable surface chemistry enable efficient adsorption of gas molecules. When volatile compounds such as ammonia, hydrogen sulfide, ethanol, aldehydes, ketones, biogenic amines, or other spoilage indicators interact with the nanosensor surface, they induce changes in electrical resistance, optical absorbance, fluorescence, or mass loading. These physicochemical changes are then translated into

quantifiable signals that can be monitored in real time. Gas nanosensors are particularly valuable in food packaging and storage systems where early detection of spoilage gases can prevent foodborne illnesses and reduce waste.

Nanomaterials significantly enhance the performance of gas sensors by increasing the rate and specificity of gas–sensor interactions. Metal oxide nanoparticles, for instance, exhibit heightened reactivity due to abundant active sites and can be doped with metals like Pt, Ag, or Pd to improve selectivity toward particular gases. Carbon-based nanomaterials such as CNTs and graphene offer exceptional electrical conductivity and surface sensitivity, enabling ultrasensitive detection of even trace levels of VOCs and spoilage metabolites. Plasmonic nanostructures—like gold or silver nanoparticles—can also be integrated to amplify optical signals, making colorimetric gas nanosensors viable for smart packaging applications where visual indications of freshness (such as color changes) are preferred. Hybrid materials combining metal oxides with carbon nanostructures further enhance sensing capabilities by improving stability, response speed, and detection limits.

Gas nanosensors are increasingly being integrated into intelligent and active packaging systems, providing consumers and supply-chain operators with real-time freshness indicators without needing to open or alter the product. These sensors can continuously track gas concentrations during transportation and storage, offering insights into microbial activity, enzymatic degradation, or oxidation processes in perishable foods like meat, fish, dairy, and fruits. However, despite their potential, gas nanosensors face challenges including sensitivity to humidity, temperature fluctuations, and cross-reactivity with non-target gases. Maintaining long-term stability and ensuring compatibility with food-packaging materials are also ongoing concerns. Current research is addressing these limitations through surface functionalization techniques, protective nanocoatings, flexible substrates, and AI-enhanced pattern recognition systems (e-noses) that interpret complex gas profiles. As advancements continue, gas nanosensors are poised to become indispensable tools in food-quality monitoring, extending shelf life, reducing waste, and enhancing safety across the entire food supply chain.

References

Abdallah, M., Errachid, A., Zine, N., & Bouchikhi, B. (2022). Recent advances in nanomaterial-based gas sensors for food quality monitoring: A review. *Trends in Food Science & Technology*, 123, 154–171. <https://doi.org/10.1016/j.tifs.2022.03.015>

- Afsahi, A., Lerner, M. B., Goldstein, J. M., Lee, J., Tang, X., & Rogers, J. A. (2020). Nanobiosensing technologies for foodborne pathogen detection. *ACS Sensors*, 5(11), 3609–3625. <https://doi.org/10.1021/acssensors.0c01730>
- Ammam, M., Belkaid, M. S., & Nebdi, H. (2021). Nanomechanical sensors for biological and food applications: Principles and recent developments. *Sensors and Actuators B: Chemical*, 330, 129333. <https://doi.org/10.1016/j.snb.2020.129333>
- Arora, P., Sindhu, A., Dilbaghi, N., & Kumar, S. (2021). Chitosan-based nanobiosensors for rapid detection of food contaminants: A review. *Food Chemistry*, 337, 127995. <https://doi.org/10.1016/j.foodchem.2020.127995>
- Arshavsky-Graham, S., & Segal, E. (2023). Nanostructured optical sensors for food safety and quality analysis. *Advanced Materials Interfaces*, 10(14), 2300045. <https://doi.org/10.1002/admi.202300045>
- Bahadir, E. B., & Sezgintürk, M. K. (2020). A review on biosensors for pathogen detection in food. *Food Chemistry*, 127196. <https://doi.org/10.1016/j.foodchem.2020.127196>
- Chen, Y., Nguyen, T., & Faith, N. (2021). Advances in gas-sensing nanomaterials for meat freshness evaluation. *Food Control*, 126, 108072. <https://doi.org/10.1016/j.foodcont.2021.108072>
- Cui, F., & Zhou, H. S. (2020). Diagnostic nanosensors for foodborne pathogens. *Nanotechnology*, 31(42), 422001. <https://doi.org/10.1088/1361-6528/aba5d2>
- Ding, S., Pi, Y., Huang, R., & Zhao, Q. (2019). Microcantilever-based nanomechanical sensors for biomolecule detection: Methods and applications. *Biosensors and Bioelectronics*, 141, 111–131. <https://doi.org/10.1016/j.bios.2019.04.040>
- Gutiérrez, M. L., López, D. P., & Molina, A. (2024). Intelligent food packaging using nanostructured gas sensors: Technological advances and challenges. *Food Packaging and Shelf Life*, 33, 101094. <https://doi.org/10.1016/j.fpsl.2022.101094>
- Khan, R., & Dhayal, M. (2020). Carbon nanotube-based electrochemical and mechanical nanosensors for food toxin detection. *Journal of Nanoscience and Nanotechnology*, 20(5), 3041–3055. <https://doi.org/10.1166/jnn.2020.17463>
- Li, Z., Fu, Y., Mei, J., & Liu, Y. (2022). Nanobiosensors based on aptamers for food contaminant detection. *Biosensors and Bioelectronics*, 207, 114203. <https://doi.org/10.1016/j.bios.2022.114203>

- Mousavi, S. A., Hashemi, M., & Ghanbarzadeh, B. (2021). Gas-sensing nanoarrays and electronic noses for food quality analysis. *Comprehensive Reviews in Food Science and Food Safety*, 20(5), 4884–4910. <https://doi.org/10.1111/1541-4337.12825>
- Rani, A., Sharma, S., & Malik, D. K. (2023). Advanced bio-nano sensors for the detection of foodborne pathogens: Applications and challenges. *Food Research International*, 165, 112596. <https://doi.org/10.1016/j.foodres.2023.112596>
- Shanbhag, V. C., Jagtap, S., & Kamble, S. (2019). Nanostructured metal oxide gas sensors for food spoilage detection: A comprehensive review. *Sensors and Actuators B: Chemical*, 297, 126743. <https://doi.org/10.1016/j.snb.2019.126743>
- Singh, A., Kaur, N., & Yadav, A. (2020). Graphene-based nanosensors for food safety applications. *Food Analytical Methods*, 13, 1134–1151. <https://doi.org/10.1007/s12161-020-01737-x>
- Wang, T., Luo, Y., & Li, X. (2023). Recent progress in nanomaterial-based biosensors for rapid detection of harmful substances in foods. *Food Chemistry*, 405, 134783. <https://doi.org/10.1016/j.foodchem.2022.134783>
- Zhang, W., Yang, S., & Li, B. (2019). Quartz crystal microbalance (QCM)-based nanomechanical sensors: A critical review of applications in food quality monitoring. *TrAC Trends in Analytical Chemistry*, 120, 115654. <https://doi.org/10.1016/j.trac.2019.115654>

NON-EXPRESSOR OF PATHOGENESIS-RELATED GENE1 (NPR1) MEDIATES THE EXPRESSION OF PATHOGENESIS

Article ID: AG-VO5-I12-11

***P.Ahila Devi, M. Shanmugapriya and K.Subrahmaniyan**

Tamil Nadu Rice Research Institute, Aduthurai, TNAU, Thanjavur District
Dr. M. S. Swaminathan Agricultural College and Research Institute, TNAU, Eachangkottai,
Thanjavur, Tamil Nadu, India

*Corresponding Author Email ID: ahila.devi1@gmail.com

Introduction

NPR genes are a diverse family of genes in plants and animals that are involved in crucial physiological processes, such as plant immunity and animal behavior. In plants, the NPR1 gene is a master regulator of salicylic acid (SA) signaling, promoting defense against pathogens through the expression of PATHOGENESIS-RELATED (PR) genes. In animals, such as the nematode *C. elegans*, NPR genes encode neuropeptide receptors that mediate responses to food and environmental cues, influencing behaviors like adaptation and quiescence. Salicylic acid (SA) is considered to be an endogenous signal molecule in plants, and it is related to many resistances in plants

In Arabidopsis, Non-expressor of pathogenesis-related gene1 (NPR1) mediates the expression of pathogenesis-related genes (PRs) and systemic acquired resistance (SAR) induced by SA.

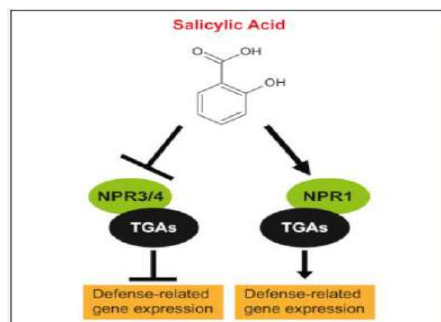


Fig 1. Salicylic acid (SA) role in synthesis of NPR genes

NPR1 is a key factor in SA signaling pathway, and the research shows that NPR1, NPR3 and NPR4 play a key role in SA mediated plant disease resistance. In this review, the interaction between NPR and transcription factors is discussed, and we also describe the progress of NPR in SA mediated SAR signal transduction pathway, likewise, we introduce the relationship between NPR1 and its paralogues NPR3/NPR4. This paper analyses the research prospect of NPR as the intersection of multiple signal paths NPR as the intersection of multiple signal paths in plants. This paper analyses the research prospect of NPR as the intersection of multiple signal paths NPR as the intersection of multiple signal paths in plants

- [NPR1](#)

(Nonexpressor of Pathogenesis-Related Genes1): This gene is a central component of the plant's defense system, particularly in [Systemic Acquired Resistance \(SAR\)](#). It acts as a transcriptional activator, turning on genes that provide broad-spectrum resistance to pathogens.

- [NPR3](#) and [NPR4](#)

: These genes also play important roles in salicylic acid (SA)-mediated plant disease resistance.

- **Regulation:**

NPR genes are part of complex signaling pathways that respond to various environmental stimuli. Their functions are being investigated to improve stress resistance in crop

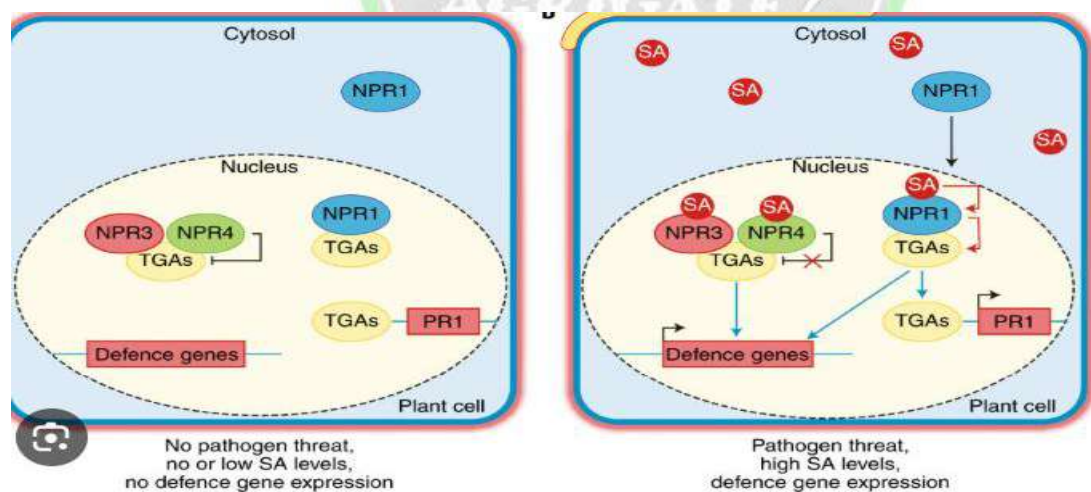


Fig 2. NPR gene regulation

NONEXPRESSOR OF PATHOGENESIS-RELATED GENES1 (NPR1)

Land plants deal with various environmental fluctuations or stresses such as shadiness, heat, and drought. Likewise, land plants are constantly surrounded by various microbes and insects and have developed sophisticated immune systems to fight off a wide range of pathogenic

organisms. Plant immune responses are controlled by diverse phytohormones such as salicylic acid (SA), jasmonic acid (JA), and ethylene (ET), among which SA has indispensable roles in both local and systemic protection against biotrophic and hemibiotrophic pathogens

In *Arabidopsis thaliana*, NONEXPRESSOR OF PATHOGENESIS-RELATED GENES1 (NPR1) is a central player in SA-mediated plant immunity. AtNPR1 is responsible for the majority of SA- or benzothiadiazole *S*-methyl ester (BTH; a functional analog of SA)-induced transcriptional reprogramming, positioning AtNPR1 as the master regulator of the regulatory defense network induced by SA in *A. thaliana*. Consistent with this, the controlled expression of AtNPR1 in rice enhances resistance against the bacterial and fungal pathogens, *Xanthomonas oryzae* pv *oryzae*, *Xanthomonas oryzae* pv *oryzicola*, and *Magnaporthe oryzae*, without compromising plant fitness, underlining the potential of NPR homologs as molecular targets or tools for the engineering of disease-resistant plants.

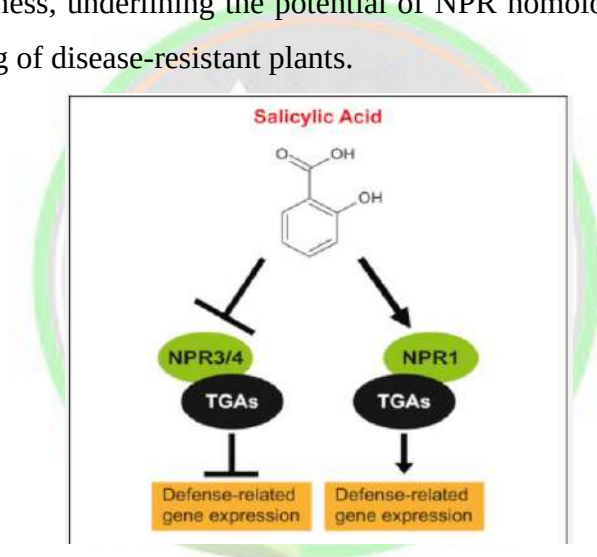


Fig 3. Salicylic acid in the modulation of defence expression

Advantages of NPR genes

NPR genes provide a wide range of advantages to plants, primarily by functioning as master regulators in plant immunity. They are crucial for establishing Systemic Acquired Resistance (SAR) and Induced Systemic Resistance (ISR), allowing for broad-spectrum defense against pathogen infections. By controlling the activation of [Pathogenesis-Related \(PR\) genes](#), NPR proteins enhance plant resistance to various pathogens, improve stress tolerance, and contribute to plant development and overall fitness, making them valuable targets for engineering disease-resistant crops.

Benefits of NPR Genes

- **Enhanced Disease Resistance:**

NPR1 and its homologues are vital for triggering broad-spectrum immunity against bacterial, fungal, and other pathogen infections by activating defense-related genes.

- **Systemic Defense Mechanisms:**

They play a central role in [Systemic Acquired Resistance \(SAR\)](#), a plant defense that provides broad immunity to the entire plant, not just the initial infection site.

- **Coordination of Defense Pathways:**

NPR genes act as master regulators, coordinating the responses to different plant defense hormones like [salicylic acid \(SA\)](#) and [jasmonic acid \(JA\)](#) to optimize defense.

- **Stress Tolerance:**

By influencing defense pathways, NPR genes can help plants respond to both biotic (pathogens) and abiotic (e.g., heat, drought) stresses.

- **Regulation of Plant Development:**

Beyond immunity, the NPR gene family also plays roles in the development of plant organs, such as leaves and flowers.

- **Improved Crop Resilience:**

The ability of NPR genes to confer disease resistance without compromising plant fitness makes them valuable tools for engineering crops, like rice, to be more resilient and productive.

How NPR Genes Work

1. **Signal Reception:** Upon pathogen attack, salicylic acid (SA) levels increase, altering the cellular redox potential and leading to the release of NPR1 from its multimeric cytoplasmic form into monomers.
2. **Nuclear Translocation:** NPR1 monomers then move into the nucleus.
3. **Gene Activation:** In the nucleus, NPR1 interacts with transcription factors (like TGA-bZIP) to activate the expression of PR genes and other defense-related genes, promoting a robust plant defense response

Advantage

Key advantages of the NPR1 gene

- **Broad-spectrum resistance:** NPR1 enhances a plant's defense against a wide range of pathogens, including fungi, viruses, and bacteria.

- Systemic Acquired Resistance (SAR): It is a key regulator for SAR, a plant's long-lasting, whole-body defense response that is activated throughout the plant after a local infection.
- Energy efficiency: Instead of being constitutively active, the NPR1 gene can be engineered to be transiently expressed only when a pathogen is detected. This prevents the potential negative impacts of a constant immune response and is more energy-efficient.
- Cross-talk with other defense pathways: NPR1 acts as a central coordinator between different plant hormone pathways (like salicylic acid and jasmonic acid), ensuring a balanced and effective defense response.
- Potential for crop improvement: Overexpression of the *AtNPR1* gene (from *Arabidopsis thaliana*) or its orthologs has been shown to improve disease resistance in numerous crops, including rice, wheat, and tomato.
- Solution for emerging diseases: This engineering approach can help protect against new diseases for which no specific resistance genes have yet evolved.

Conclusion And Future Directions

Since its discovery more than 20 years ago, NPR1 has been the focus of countless studies. During this time several NPR1-dependant pathways have been uncovered as have many of the complex mechanisms governing the regulation of NPR1. However, much is still left unanswered, owed to the multifaceted relationships that exist between NPR1, its paralogs and their interacting partners. Truly grasping the extent of such interactions requires an increased effort to discover novel interactions in different species, tissues and during plant–pathogen specific interactions. A topic pursuant to this which is severely underrepresented in the literature is that of tissue specific regulation of NPR1-dependant pathways.

Volume: 05 Issue No: 12

UNLOCKING ARTIFICIAL INTELLIGENCE (AI) AND MACHINE LEARNING (ML) FOR SMART AGRICULTURE: A BASIC UNDERSTANDING

Article ID: AG-VO5-I12-12**Dr. Rajib Roychowdhury***

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT),
Hyderabad 502324, India

*Corresponding Author Email ID: rajibroychowdhury86@yahoo.com

Introduction

Agriculture today is a complex interplay of soil, water, climate, crops, pests, and markets. Farmers make countless decisions each season—when to sow, irrigate, spray, harvest, and sell. These decisions are becoming harder due to climate variability, resource constraints, and market volatility. Artificial Intelligence (AI) and Machine Learning (ML) offer a new way forward by transforming raw data into actionable insights. For smallholder farmers in India, where rainfed farming dominates, AI and ML can help reduce risks, improve productivity, and cut costs. They enable better decisions on irrigation, pest control, and crop management, while providing early warnings for diseases and weather extremes. In short, AI and ML are not futuristic buzzwords; they are practical tools that can make farming smarter and more resilient. This article demystifies AI/ML in simple terms, shows what they do on real farms, and explains how farmers, researchers, startups, and governments can make them work on the ground.

Understanding AI and ML in Simple Terms

AI refers to machines performing tasks that mimic human intelligence—such as recognizing patterns, making decisions, and learning from experience. In agriculture, AI powers crop recognition from images, automated machinery guidance, predictive advisories, and even conversational assistants for farmers. ML is a subset of AI that focuses on learning from data. Instead of programming every rule, ML algorithms learn patterns from examples and improve over time. For instance, an ML model can learn to distinguish healthy leaves from diseased ones by analyzing thousands of labeled images. Over time, the model becomes more accurate as it

processes more data. Imagine teaching a teen how to drive: at first you explain the basics, then they practice a lot, get feedback, and improve. ML is similar, data are the “driving lessons” and the model’s accuracy improves with more practice, better feedback, and clearer objectives. This ability to learn and adapt makes ML particularly powerful for agriculture, where conditions vary widely across regions and seasons. There are three ML approaches are used:

- **Supervised Learning:** It is like teaching with an answer key. The model is trained on a dataset where each example has a known label or outcome. For instance, if you want to detect plant diseases, you provide the algorithm with thousands of images labeled as “healthy leaf” or “leaf spot.” The model learns the relationship between input features (image pixels) and the correct output (disease status). Once trained, it can predict labels for new, unseen data. This approach is widely used for classification (e.g., pest identification) and regression tasks (e.g., predicting crop yield).
- **Unsupervised Learning:** It works without labeled data. The algorithm explores the dataset to find hidden patterns or groupings. For example, if you have soil moisture readings from hundreds of fields, the model can cluster them into groups with similar moisture trends. Farmers in each cluster can then receive tailored irrigation advice. This method is useful for market segmentation, anomaly detection, and identifying natural groupings in complex agricultural datasets.
- **Reinforcement Learning:** It is based on trial and error, guided by rewards. The model interacts with an environment, takes actions, and learns which actions yield the best outcomes over time. For example, an irrigation scheduling system can experiment with different watering intervals and volumes, receiving feedback in terms of crop health and water savings. Over time, it learns an optimal strategy that maximizes yield while minimizing water use. This approach is ideal for dynamic decision-making in resource management.

The Data Behind AI on the Farm

AI and ML thrive on data, and agriculture provides a diverse yet fragmented data ecosystem. Modern farms generate information from multiple sources, each offering unique insights into crop health, soil conditions, and market dynamics. Sensors and Internet of Things (IoT) devices installed in fields measure soil moisture, temperature, and leaf wetness, while automated weather stations record rainfall and humidity. Drones and satellites capture

multispectral imagery that helps track crop growth, detect stress, and map variability across large areas. Farmers themselves contribute valuable data through smartphones by uploading photos for pest and disease diagnosis or entering agronomic details into mobile applications. Machinery telemetry adds another layer, reporting fuel consumption, operational patterns, and location data from tractors and implements. Beyond the farm gate, market and logistics data—such as price trends, demand signals, storage conditions, and transport routes—inform decisions on harvest timing and sales. At the research level, genomic and phenomic datasets guide breeding programs, enabling precise variety selection and trait prediction. However, the quality of data determines the success of AI-driven solutions. Good data are timely, consistent, and representative, while poor-quality data can mislead models and result in inaccurate recommendations. Building a robust pipeline for data collection, cleaning, validation, and privacy protection is therefore critical. Without these safeguards, even the most advanced algorithms cannot deliver reliable insights. In short, data is the foundation of smart agriculture, and its integrity is non-negotiable.

What AI/ML Actually Do in Smart Agriculture

- **Precision Agronomy - Right Input, Right Time, Right Amount:** Precision agronomy uses AI and ML to ensure that crops receive exactly what they need, when they need it. Site-specific recommendations help farmers apply fertilizers, water, and pesticides only where required, reducing waste and improving soil health. Variable Rate Technology (VRT) employs machine learning maps to fine-tune field operations, while Decision Support Systems (DSS) integrate weather forecasts, sensor readings, and crop models to provide actionable advisories. The result is reduced input costs, healthier soils, and improved yields.
- **Crop Health Monitoring and Diagnostics:** AI-powered computer vision can analyze images of leaves and pods to detect pests and diseases at an early stage. Machine learning classifiers trained on local datasets distinguish between common issues, such as Maruca versus Helicoverpa damage in pigeonpea, with minimal effort from farmers. Alert systems notify growers before outbreaks peak, enabling timely and targeted interventions. This leads to less crop loss, lower pesticide use, and safer food for consumers.
- **Yield Estimation and Forecasting:** Yield prediction is another area where ML excels. Time-series models such as random forests, gradient boosting, and LSTMs combine weather data, remote sensing, and management practices to forecast yields accurately. In-

season predictions allow farmers to plan harvest logistics, storage, and marketing strategies, reducing post-harvest losses and improving cash flow.

- **Irrigation Optimization:** AI-driven irrigation systems use soil moisture data, weather forecasts, and crop growth stages to recommend optimal watering schedules. Reinforcement learning further refines these strategies by learning from past actions to save water while maintaining yields. This approach ensures water and energy savings and enhances resilience during dry spells.
- **Weed and Pest Management:** Machine learning models can identify weed species through image recognition, enabling robots or drones to perform targeted weeding or spraying. Herbicide decision models suggest precise dosages and timings, integrated with tolerance data for future herbicide-ready cultivars. These innovations reduce labor burdens, minimize chemical inputs, and sustain crop yields.
- **Climate-Smart Advisories:** Seasonal climate models and downscaled weather data feed into ML tools that predict heat stress, excess rainfall, or drought conditions. Phenology prediction helps farmers adjust sowing and harvesting schedules to mitigate risks. This proactive approach supports better risk management under climate variability.
- **Livestock and Fisheries (Bonus Outlook):** AI applications extend beyond crops. Wearable sensors and cameras track livestock behavior, detecting illness early and prompting timely veterinary care. In aquaculture, ML models monitor water quality and predict feed conversion efficiency, optimizing operations for higher productivity and healthier animals.

Tools and Technologies Driving AI in Agriculture

Smart agriculture relies on a combination of **hardware** and **software**. **Hardware** is the backbone of smart agriculture begins with accessible devices. Smartphones are the most ubiquitous and affordable entry point, serving as gateways for farmers to receive digital advisories and upload field data. Sensors installed in fields measure soil moisture, temperature, and humidity, while automated weather stations provide real-time climate information. Drones equipped with high-resolution cameras capture frequent crop images, enabling detailed monitoring of plant health and stress. Satellites complement this by offering wide-area imaging through indices like NDVI and EVI, which help track growth patterns and detect anomalies. Edge devices, such as small computers placed near fields, process data locally to reduce

bandwidth needs and ensure faster decision-making. Autonomous machines, including GPS-guided tractors, sprayers, and planters, bring precision to field operations, minimizing waste and improving efficiency. On the **software** side, mobile applications deliver agronomy advisories, integrate marketplaces, and provide calculators for input management. Geographic Information Systems (GIS) and remote sensing platforms enable mapping of variability and change detection across landscapes. Modeling and analytics tools, powered by machine learning libraries like TensorFlow and scikit-learn, support predictive insights and dashboard visualizations. Cloud services offer scalable storage and computing power, making advanced ML pipelines accessible to startups and cooperatives. Application Programming Interfaces (APIs) and integration frameworks link weather services, market data, and government schemes, creating a unified ecosystem. Interoperability—where systems communicate seamlessly—remains the key to transforming isolated gadgets into a cohesive smart farm network.

Benefits for Farmers and Agri-business

- **Economic Gains:** Artificial Intelligence and Machine Learning deliver tangible economic benefits to farmers and agribusinesses. Precision recommendations for fertilizer, water, and pesticide application reduce input costs significantly. Yield improvements achieved through targeted management practices translate into higher productivity and better profitability. Additionally, accurate demand forecasts and harvest timing advisories help farmers secure better prices in the market. These gains can be measured using indicators such as gross margins, benefit–cost ratios, and the payback period for digital tools, providing clear evidence of economic impact.
- **Environmental and Social Gains:** Smart agriculture powered by AI also contributes to environmental sustainability and social well-being. By optimizing input use, emissions and chemical runoff are minimized, reducing the ecological footprint of farming. Automated or targeted interventions lessen manual labor requirements, easing drudgery for farmers and farm workers. Furthermore, reduced pesticide use and improved residue management ensure safer food for consumers. These outcomes can be quantified through metrics like input intensity per hectare, water-use efficiency, pesticide residue levels, and labor hours saved.

- **Knowledge Empowerment:** Perhaps the most transformative benefit lies in knowledge empowerment. Farmers gain confidence when their decisions are backed by data-driven insights and timely advisories. Community learning accelerates adoption as groups test and share experiences with digital tools. This collective approach fosters trust and builds resilience. Success in this domain can be measured through adoption rates, repeat usage statistics, satisfaction surveys, and peer-to-peer referrals, all of which indicate how deeply technology is integrated into farming practices.

Test Cases in an Indian Perspective

- **Smart Irrigation in Semi-Arid Villages:** In semi-arid regions of India, water scarcity is a persistent challenge. AI-driven irrigation systems have demonstrated remarkable success by integrating soil moisture sensors, local weather data, and crop growth stage information into mobile applications. These apps provide precise irrigation schedules, enabling farmer groups to rotate shared pumps efficiently. Such interventions have resulted in water savings of 20–30% while maintaining or even improving crop yields, proving that technology can make resource management both sustainable and profitable.
- **Pest Early-Warning for Pigeonpea:** Pigeonpea farmers often struggle with pod borer infestations, which can devastate yields. AI-powered pest monitoring systems now allow village scouts to upload weekly crop images via smartphones. Machine learning algorithms classify damage symptoms and send timely alerts to farmers. This enables community-level Integrated Pest Management (IPM) actions, such as deploying pheromone traps and applying biocontrol sprays at the right time. The outcome is fewer chemical sprays, reduced crop losses, and safer food production.
- **Weed Mapping for Targeted Spraying:** Weed infestation increases labor costs and reduces productivity. In several Indian cooperatives, drones equipped with imaging sensors map weed hotspots across fields. These maps guide GPS-enabled sprayers to apply herbicides only where needed, cutting chemical use and labor expenses significantly. By sharing one drone and sprayer among multiple farmers, cooperatives make advanced technology affordable and accessible.
- **Market Timing:** AI-based yield forecasting tools combined with local mandi price trends help farmers make informed decisions about storage and sales. By staggering

harvest and marketing schedules, farmers avoid market gluts and secure better prices. This predictive approach improves income stability and reduces post-harvest losses.

- **Breeding Support:** Machine learning is also revolutionizing crop breeding. By integrating phenotypic, genotypic, and environmental data, ML models rank breeding lines for yield stability and stress tolerance. Breeders use interactive dashboards to select parents and trial sites more efficiently, accelerating the development of improved varieties tailored to local conditions.

Designing AI/ML Solutions for Farmers, Villages, Cooperatives, Policy and Ecosystem Enablers:

A human-centered approach is key to successful adoption. Co-creation with farmers during pilot projects ensures that tools address real needs. Recommendations should be simple, offering two or three clear actions rather than overwhelming details. Local calibration is essential to reflect soil, variety, and climate conditions. Farmers should be given choices—chemical, biological, or cultural—with associated costs and benefits. Community-based models, where cooperatives share devices and learn together, accelerate trust and adoption. Demonstration plots and dashboards help visualize savings and yield gains. Support should cover the entire crop cycle, from pre-sowing variety selection to in-season irrigation and pest alerts, and post-harvest storage and marketing. A practical toolkit for rural communities includes an offline-capable weather and advisory app in local languages, one automatic weather station maintained cooperatively, and two to three soil moisture sensors rotated across fields. A shared drone or RGB camera can provide crop scouting every two to three weeks. Extension champions—trained local youth—can assist with data collection and app usage. Simple consent forms and a community data registry ensure transparency. Within one season, farmers can expect water savings, fewer pesticide sprays, and better yields. Over two to three seasons, models become more accurate, and benefits scale across the community.

Policy frameworks must support open data standards and interoperability so that tools can work together seamlessly. Digital Public Infrastructure (DPI) should include registries and APIs for weather, soil, and market data. Investments in capacity building—digital extension, farmer training, and rural innovation hubs—are essential. Incentives should reward measurable outcomes such as water savings and reduced pesticide use. Ethical frameworks must ensure data

protection, informed consent, and non-discrimination, creating a trustworthy environment for technology adoption.

Current Challenges and Limitations

- **Data Quality and Localization:** One of the biggest challenges in deploying AI and ML in agriculture is data quality. Models trained on global datasets often fail when applied locally because soil types, climate, and cropping patterns vary widely. To overcome this, local datasets must be built and updated regularly. Farmers and extension teams should be involved in data collection to ensure relevance. Seasonal model calibration and strict quality assurance protocols for images and sensor readings are essential to maintain accuracy.
- **Infrastructure and Cost:** Connectivity gaps, high device costs, and maintenance burdens limit technology adoption in rural areas. Solutions include developing offline-first applications that work without continuous internet access, promoting shared infrastructure such as cooperative-owned drones and weather stations, and introducing pay-per-use models. Integration with public schemes and CSR programs can further reduce financial barriers for smallholders.
- **Skills and Trust:** New technologies often face resistance due to lack of awareness and trust. Farmer field schools can provide hands-on training, while on-call support ensures timely troubleshooting. Explainable AI outputs that clearly state why a recommendation was made build confidence. Delivering advisories in local languages and avoiding technical jargon makes tools more inclusive and farmer-friendly.
- **Sustainability and Ethics:** Data privacy, algorithmic bias, and overuse of chemicals are critical concerns. Consent-based data sharing and anonymization should be standard practice. Models must be trained fairly across regions to avoid bias. Advisories should embed principles of integrated pest management and nutrient stewardship, and environmental outcomes should be monitored to ensure sustainability.
- **Fragmentation of Solutions:** The proliferation of apps and devices that do not communicate with each other creates inefficiencies. Open standards, APIs, and integrated platforms are needed to ensure interoperability. Policy support for unified digital ecosystems will make smart farming solutions scalable and farmer-centric.

Future prospects:

The future of AI in agriculture promises exciting innovations. Explainable agronomy AI will make recommendations transparent, stating reasons such as humidity levels or pest counts. Multi-modal sensing will combine satellite, drone, ground sensors, and farmer inputs for richer insights. Genomics integrated with AI will accelerate breeding by predicting genotype-environment interactions and enabling speed breeding for location-specific varieties. Low-cost autonomous robots for weeding and spraying will become accessible through shared service models. AI-powered risk scoring will link farmers to microcredit and weather insurance, reducing vulnerability and improving resilience.

Conclusion

AI and ML are not magic solutions; they are tools that complement farmer knowledge. When combined with good data, local calibration, and participatory approaches, they can help farmers produce more with fewer resources. For India's smallholders, AI offers a pathway to higher productivity, lower costs, and greater resilience. The journey requires collaboration among farmers, researchers, startups, and policymakers. Together, we can unlock the potential of AI and ML to build a sustainable and profitable future for agriculture.

GROWING SHADOW OF SCRUB TYPHUS IN TAMIL NADU

Article ID: AG-VO5-I12-13

Dr. Vivekanandhan R*

Assistant Professor, Department of Veterinary Public Health and Epidemiology,
Veterinary College and Research Institute, Udumalpet – 642 205, Tamil Nadu

*Corresponding Author Email ID: vivekrmvc22@gmail.com

Introduction

Scrub typhus or bush typhus is a neglected zoonotic disease. This means that zoonotic diseases mainly affect the poor and marginalised populations of low-resource settings. Scrub typhus is caused by *Orientia tsutsugamushi*, an intracellular Gram-negative bacterium belonging to the Rickettsiaceae family. Scrub typhus is spread to humans by the bite of trombiculid or chigger mites.

Epidemiology

Did you know that scrub typhus infects close to a million of people around the world each year? It mostly affects the people of village areas who often work in places covered with shrubs and bushy types of vegetation in their day-to-day life, people who live in close proximity to the forest, forest campers and the people going for frequent trekking.

Scrub typhus was once believed to occur only within the “Tsutsugamushi Triangle.” In recent days, due to climate change, land use, intense agriculture, deforestation, encroachment into wild niches and growing populations, scrub typhus is quietly becoming a growing shadow of concern in Tamil Nadu. In Tamil Nadu, all the districts were endemic for scrub typhus, with Dindugul district reporting the highest positivity rate of 43%, while only the Nilgiris and Madurai showed lower levels (Rathinasamy *et al.*, 2024). According to the Directorate of Public Health, 5000 cases were reported in Tamil Nadu during 2024 (The Hindu, 2025).

Transmission

Scrub typhus spreads to humans and animals through the bite of the tiny larval stage of

mites called chiggers or trombiculid mites (*Leptotrombidium deliensei*). They are very minute in size, which are not visible to the naked eye and can be seen only through a microscope. So, it is impossible to know whether the mite is in the body. These chiggers usually don't drink blood. They feed on the body's tissue fluids.

In nature, chiggers become infected when they feed on small animals like rodents, which maintains the infection. Once the mite becomes infected with bacteria, it carries it throughout its entire life. They even pass it to their eggs, which means new generations of mites born already are infected. This keeps the infection circulating in the environment even without frequent contact with infected animals. While feeding on humans, these mites release saliva that contains a large number of *O. tsutsugamushi* bacteria. This saliva enters the human body during feeding and that could pose infections in humans.

Clinical signs in Humans

It causes acute febrile illness in infected humans, such as severe headache and body pain, cough, rashes and gastrointestinal symptoms. At the site of a chigger mite bite, a small papule will develop, central necrosis will occur and a black eschar resembling a cigarette burn will form. In untreated cases, scrub typhus even cause severe internal organ damages. Scrub typhus having case fatality up to 70% (Bedi *et al.*, 2022).

Diagnosis

Scrub typhus can be diagnosed using several reliable tests, such as ELISA and IFA blood tests, rapid card tests (ICT), the traditional Weil–Felix test and modern molecular techniques like PCR and LAMP assay can be used.

Treatment

Doxycycline is considered as the drug of choice for scrub typhus. It can be used for treating the infected persons after consulting with the physicians.

Prevention and control

Currently, there are no effective vaccines available for scrub typhus. So, prevention and control measures should focus on reducing the vector and reservoir population. Mite problems can be managed effectively by applying cold fogging or Ultra Low Volume spraying with pyrethrum-containing insecticides. Clear the bushes and unwanted vegetation from the living places, which will help to control the mite population. Wear suitable clothing while conducting outdoor activities such as camping or trekking, such as light coloured long sleeved shirts, long

trousers tucked inside the boots and wearing of hats to reduce exposure.

Use of insect repellents such as DEET, benzyl benzoate, IR3535 and picaridin on the skin helps to get rid of these mite infestations. Rodent population can be controlled by applying rodenticides or placing rodent traps around the surrounding areas.

Reference

Bedi, Jasbir Singh, Deepthi Vijay, and Pankaj Dhaka. 2022. Scrub Typhus. 1st Edn. Textbook of zoonoses. John Wiley & Sons. Hoboken, New Jersey, United States. 396p

Rathinasamy A., Amudha, Ramasamy Sankarmani., Mathivanan., Thangarasu S., Elangovan V., Krishnaveni P., et al 2024. Trend of Scrub Typhus in Tamil Nadu – 2021-2023 (Based on IHIP Data). TamilNadu J. Public Health Med. Res. 4(1): 69-73.

Scrub typhus guidelines by the Directorate of Public Health and Preventive Medicine

The Hindu, 2025. DPH releases guidelines for the prevention of scrub typhus.
<https://www.thehindu.com/news/national/tamil-nadu/dph-releases-guidelines-for-prevention-of-scrub-typhus/article69050204.ece>

Volume: 05 Issue No: 12

CHARACTERIZATION AND UTILIZATION OF PRE- AND POST-CONSUMER SILK WASTE: TOWARDS SUSTAINABLE TEXTILE PRODUCTION

Article ID: AG-VO5-I12-14

***Sabiya Sulthana M., Utchimahali T., Pavithra N., Padma Priya R., Lokesh Kumar P and
Basavaraj Somalingappa Purad**

Department of Sericulture, Forest College and Research Institute, TNAU, Mettupalayam,
Tamil Nadu, India

*Corresponding Author Email ID: sabiyahabeebm10@gmail.com

Abstract

The management of silk waste represents a critical evolution within the textile industry, marking a transition from a linear disposal model to a circular, value-driven framework. Historically considered an inevitable byproduct, silk waste is now recognized as a versatile and valuable resource. This paper delineates the valorization pathways for silk waste, from established commercial applications—including the production of spun silk yarns, non-woven textiles, and sericin-based cosmetics—to cutting-edge innovations in biomedicine and advanced materials. These strategies, grounded in circular economy principles, demonstrate how the systematic repurposing of waste streams can simultaneously mitigate environmental impact, foster economic resilience, and drive technological progress. The holistic integration of these approaches is posited as essential for ensuring the long-term sustainability and competitiveness of the global silk sector.

Introduction

Silk, often hailed as the queen of textiles, is one of the most luxurious and sought-after natural fibers in the world. Renowned for its exceptional softness, natural sheen, and strength, silk has been integral to the global textile industry for centuries. Originating from the delicate cocoons of silkworms, silk production—or sericulture—combines age-old traditions with modern techniques to create a fabric that is both timeless and versatile. Despite its high value, silk production inevitably generates substantial waste, including short fibers and defective

cocoons. Recycling this silk waste not only supports sustainability but also opens new avenues for innovation, making the textile industry more eco-friendly and economically efficient. Understanding the benefits of recycling silk waste is essential for fostering sustainable development in this prestigious and rapidly evolving sector.

What is Silk Waste?

Silk waste refers to raw silk fibers and materials that are unsuitable for producing continuous silk threads due to their short length, defects, or damage. It is generated at multiple stages of the silk production process and consists of several types:

Reeling Waste: This includes broken or tangled silk filaments that occur during the initial unwinding of silk from cocoons. These shorter fibers cannot be reeled into long continuous threads and are considered residual silk.

Spinning Waste: Produced when shorter silk fibers are spun into yarn rather than reeled, this waste arises from blending silk scraps and coarse fibers that do not meet filament quality standards.

Throwing and Weaving Waste: This category includes yarn ends, selvages (edges), trimmings, and defective fabric pieces generated during weaving and fabric finishing processes.

Cocoon Waste: Consists of imperfect, crushed, or damaged cocoons that cannot be used for continuous silk filament production, including those with moth exit holes or incomplete structure.

Collectively, these wastes account for a significant portion of silk production—often 20-30% or more—and represent a valuable resource that can be recycled or upcycled rather than discarded. Managing silk waste effectively helps reduce environmental impact while providing raw materials for alternative silk products and sustainable textile innovations.



Reeling waste

Reeling waste refers to the leftover silk fibers and materials produced during the process of unwinding silk filaments from cocoons to create continuous silk threads. This waste consists primarily of shorter, broken, or tangled fibers that cannot be reeled into long, continuous silk threads due to their length or defects. It includes damaged or incomplete cocoons, such as those pierced by moths, which disrupt the filament's continuity. During reeling, some silk breaks or tangles, resulting in additional waste that retains the sericin, the gummy substance coating the silk fibers. Although considered a byproduct, reeling waste is a valuable resource. It is often processed further into spun silk yarns and blended fabrics through carding and degumming, contributing to sustainable silk production by minimizing waste and providing raw materials for alternative silk products

Spinning waste

Spinning waste in the silk industry encompasses various byproducts generated during the conversion of short or defective silk fibers into spun yarns, which are distinct from the continuous filaments produced in reeling. This waste is produced in several stages of the spinning process, including carding, combing, drawing, roving, and ring spinning. The waste types can be broadly categorized into soft waste and hard waste. Soft waste, such as lap bits, sliver bits, roving ends, and pneumafil waste, contains relatively open fibers that can be directly reused in earlier processing steps to produce coarser yarns or blended products. Hard waste, generated in later stages like ring spinning and winding, consists of denser fiber masses requiring additional processing before reuse. Common spinning wastes include noil, sliver cuts, web waste, and carding waste, which contain fibers of varying lengths and qualities mixed with impurities such as dust and seed coats. Efficient management of spinning waste is vital to reducing fiber loss, improving yarn quality, and enhancing sustainability. By recycling spinning waste, silk industries can produce value-added yarns for products such as upholstery, blankets, and blended textiles, ensuring that shorter fibers contribute meaningfully instead of being discarded. Proper waste handling balances minimization of material loss with maintaining desired yarn properties, thus supporting both economic and environmental goals in sericulture and textile production.

Throwing and weaving waste

Throwing and weaving waste in silk production refers to the byproducts generated after

the reeling process, during the subsequent silk throwing and weaving stages. Throwing waste, also known as throwster's waste, is the silk waste produced when raw silk threads are twisted and doubled together to create stronger yarns suitable for weaving. This waste includes short fibers, broken threads, yarn ends, selvages (fabric edges), and yarn trimmings that result from twisting, winding, and preparation processes. It typically undergoes cleaning and degumming (removal of sericin) before reuse.

Weaving waste comprises the remnants from fabric production such as defective or cut fabric pieces, selvage edges, knots, and trimmings that do not meet quality standards. These wastes accumulate during the weaving and finishing processes and are often recycled into spun silk or other blended yarns. Both throwing and weaving wastes represent discontinuous silk fibers that cannot be used for producing **continuous** filament yarns but serve as valuable raw materials for varied silk textile products after processing.

Cocoon waste

Cocoon waste in sericulture includes several types of defective or unusable cocoons that cannot be processed into continuous silk filaments. These types encompass pierced cocoons from which moths have emerged, damaged or crushed cocoons resulting from handling, double cocoons spun by two silkworms together, and stained or discolored cocoons that affect fiber quality. Additionally, flimsy or thin-shelled cocoons with low silk content, malformed or irregularly shaped cocoons, and coarse outer layers or shell pieces are classified as cocoon waste. Scrap fibers and particles generated during cocoon opening and sorting processes also contribute to cocoon waste. Collectively, these wastes form a significant portion of the total cocoon weight but are valuable for producing spun silk yarns and other bio-based products, thereby enhancing resource efficiency and sustainability in the silk industry.

Traditional and Commercial Uses of Silk Waste

For centuries, the silk industry has operated on principles of efficiency, leading to the development of robust markets for its by-products. These traditional uses form the backbone of silk waste valorization, turning potential loss into economic gain and reducing environmental impact.

1. Spun Silk Yarns: This is the most significant and well-established use of silk waste. Since short fibers cannot be reeled into continuous filaments, they are spun together—much like cotton or wool—to create unique and valuable yarns.

The Manufacturing Process:

1. **Sorting and Degumming:** Different types of waste (e.g., frisons, blaze, cocoon waste) are sorted and then boiled in a soap solution to remove the sericin gum. This is a crucial step to soften the fibers and prepare them for spinning.
2. **Opening and Dressing:** The degummed, matted mass of fibers is passed through machines with pinned rollers to "open" it, separating and aligning the individual fibers.
3. **Combing:** The fibers are combed to remove any remaining impurities and to separate the longer fibers from the very shortest ones (noils). This step determines the final yarn quality.
4. **Spinning:** The prepared fibers, now called a "sliver," are drawn out and twisted on spinning frames to form a cohesive yarn.

Types of Spun Silk Yarns:

Schappe Silk: Made from the **longer grades of silk waste** (e.g., better-quality reeling waste), which are carefully degummed and combed.

Characteristics: This is the **highest quality of spun silk**. It has a relatively smooth surface, a soft, luxurious hand-feel, and a characteristic, subtle luster that is denser than the shine of reeled silk but less brilliant.

Uses: High-end apparel, luxury knitwear (sweaters, cardigans), linings, and ties. Schappe silk is prized for its durability and comfort.

Bourette Silk: Spun from the "**noils**"—the very short, coarse, and irregular fibers removed during the combing process of schappe silk production. It intentionally incorporates the small, nubby bits and specks.

Characteristics: Bourette silk is defined by its **rustic, textured, and nubby appearance**. It has a slubbed, uneven surface and a more matte finish. The term "bourette" comes from the French word for "noil."

Uses: Fashion fabrics where a textured, "raw" look is desired. It is used in suits, jackets, upholstery, and decorative fabrics. Its unique aesthetic makes it a favorite among designers seeking a natural, artisanal feel.

2. Non-Woven Textiles

Silk waste that is too short or low-grade for spinning is perfectly suited for non-woven applications.

Process: The short fibers are cleaned, carded to align them roughly, and then bonded together using mechanical (needle-punching), chemical (adhesives), or thermal (using the fiber's own protein) methods.

Products:

Silk Felt: A dense, matted fabric used for high-end millinery (hats), polishing cloths for delicate surfaces (eyeglasses, jewelry), and craft applications.

Padding and Insulation: Silk floss (a loose, fluffy mass of waste silk) is an exceptional filling material. It is used in luxury quilts, jackets, and sleeping bags because it is lightweight, highly breathable, and has excellent thermal regulation properties. It is also used as sound-dampening insulation in high-fidelity audio equipment.

3. Sericin in Cosmetics

The wastewater from the degumming process, once a major pollutant, is now a valuable resource for the cosmetic and personal care industry.

Recovery: Sericin is recovered from the degumming bath through various methods like ultrafiltration, precipitation, and drying.

Functional Properties:

Moisturization: Sericin is a natural humectant, meaning it helps the skin retain moisture, leaving it soft and supple.

Anti-Aging & Antioxidant: It helps protect the skin from free radical damage caused by UV exposure, which can lead to wrinkles and fine lines.

Wound Healing: It promotes skin cell proliferation and migration, aiding in repair.

Applications: Found in a wide array of products including moisturizing creams, lotions, serums, facial masks, shampoos, conditioners, and soaps.

4. Fertilizer & Animal Feed

After the silk filament is reeled off, the leftover silkworm pupae inside the cocoon represent a significant biomass.

Nutritional Profile: The pupae are **extremely rich in protein (50-60%)**, lipids (oils), vitamins (especially B complex), and minerals.

Processing and Uses:

Drying and Grinding: The pupae are dried and ground into a nutrient-dense meal.

Animal Feed: This **silkworm pupae meal** is a high-protein component in feed for poultry, fish (aquaculture), and pigs. It is a sustainable alternative to fishmeal.

Fertilizer: The pupae meal or composted waste can be used as an organic fertilizer, enriching soil with nitrogen and other essential nutrients.

Pupae Oil: The oil extracted from pupae is used in animal feed and has potential industrial applications in the production of soaps and lubricants.

Conclusion

Silk waste has undergone a significant paradigm shift, transforming from an unavoidable industrial byproduct into a valuable multi-purpose resource. This journey from waste to wealth is anchored in both traditional practices—such as the production of distinctive spun silk yarns and the use of pupae for feed—and modern, high-value innovations in cosmetics, biomedicine, and material science. These advancements underscore a critical alignment with circular economy principles, where waste is eliminated, and resources are continually repurposed. By systematically valorizing every stage of its production waste, the silk industry not only mitigates its environmental footprint but also unlocks new avenues for economic growth and technological innovation. Ultimately, embracing a holistic approach to silk waste is indispensable for forging a more sustainable, resilient, and profitable future for this historic global sector.

Reference

- Gaviria, M. I., Quintero, J. S., & Monteiro, S. N. (2023). Silk wastes and autoclaved degumming as an alternative for a sustainable silk process. *Scientific Reports*, 13, 15296.
- Grand View Research. (2024). *Silk market size, share & trends analysis report by type (mulberry, tussar, eri), by application (textile, cosmetics), by region (APAC, North America, Europe, MEA), and segment forecasts, 2024 - 2030* (Report GVR-4-68039-841-9).
- MDPI Blog. (2024, December 13). Using recycled silk can help combat pollution in waterways.
- Puglia, D., & Monti, M. (2025). Potential use of silk waste in sustainable thermoplastic composite material applications: A review. *Fibers*, 13(1), 6.
- Roy, R., & Akter, M. (2025). Transitioning the silk industry towards circularity. *Science of The Total Environment*, 958, 177321.

FUNGAL DEFENSE IN PLANTS: THE ROLE OF THAUMATIN-LIKE PROTEINS

Article ID: AG-VO5-I12-15

**Sri Meenakshi Sundaram K.V., Samuel P., Mohana Priya S., Deepa G., Akilan M.,
Anuradha C.***

ICAR-National Research Centre for Banana

Thogamalai Road, Thayanur Post, Tiruchirappalli - 620 102. Tamil Nadu, India.

*Corresponding Author Email ID: anuradha.chelliah@gmail.com

Introduction

Plants are immobile organisms that cannot escape when faced with adverse environmental conditions. To survive, they have developed sophisticated defense systems to cope with a wide range of stresses — from biotic threats (such as pathogens and pests) to abiotic challenges (such as drought, salinity, and extreme temperature fluctuations). Upon detection of a pathogen, many plants rapidly activate immune responses, including a pronounced induction of a class of proteins known as pathogenesis-related (PR) proteins (Feng et al., 2024; Zhu & Schreiber, 2024). PR proteins are encoded by the plant genome and are produced in response to various stress signals; their roles extend beyond pathogen resistance, often contributing to broader stress tolerance under unfavorable environmental conditions (Edreva, 2005). Based on sequence similarity, serological relationships, and biochemical activity, PR proteins have been classified into 17 distinct families (Liu et al., 2010; Souza et al., 2017; Zhu & Gao, 2025). Among these, the PR-5 family, comprising the thaumatin-like proteins (TLPs), stands out as one of the most widely distributed and functionally important groups (Liu et al., 2010; Sels et al., 2008).

Thaumatin-like proteins (TLPs) are named after their high sequence similarity to thaumatin, a sweet-tasting protein first isolated from the African plant *Thaumatococcus daniellii* (Ren et al., 2022). TLPs are found throughout the plant kingdom, including angiosperms, gymnosperms, and even more basal plants, which highlights their evolutionary conservation and significance in plant defense (van Loon et al., 2006). Structurally, many TLPs carry a conserved

domain characteristic of the “thaumatin-fold,” often stabilized by multiple disulfide bonds — features that likely contribute to their stability under stress conditions (Sels et al., 2008).

Classification and Structure of TLPs

TLPs are highly conserved defense polypeptides belonging to the pathogenesis-related protein family 5 (PR-5) and are among the most functionally significant PR proteins in plants (Liu et al., 2010). These proteins are ubiquitously distributed across the plant kingdom and have also been identified in other kingdoms, including fungi and animals, reflecting their evolutionary conservation and functional importance in stress adaptation (Edreva, 2005). Structurally, TLPs typically comprise approximately 200 amino acids and are characterized by a conserved consensus sequence, including 16 cysteine residues that form eight disulfide bonds, which are essential for maintaining structural stability under various stress conditions (Liu et al., 2010; Yan et al., 2017). Based on molecular weight and cysteine content, TLPs are generally classified as “large” (~22–26 kDa) or “small” (~16–18 kDa) proteins, with the smaller isoforms arising from internal deletions while retaining the conserved thaumatin fold (Liu et al., 2010).

The PR-5 family encompasses multiple functional subgroups that differ in sequence features, localization, and biological roles. Canonical TLPs are extracellular proteins homologous to thaumatin and often act directly in pathogen defense (Ren et al., 2022). Osmotin-like proteins (OLPs) are basic isoforms predominantly localized to the vacuole and were initially described as salt-induced proteins in osmotically stressed tobacco cells (Edreva, 2005; Liu et al., 2010b). Permatins, including zeamatin from maize, hordomatin from barley, and avematin from oats, are PR-5 proteins concentrated in cereal seeds and are hypothesized to form transmembrane pores (Liu et al., 2010). PR5-like receptor kinases (PR5K) are chimeric proteins identified in Arabidopsis and rice, comprising an extracellular TLP domain coupled to an intracellular kinase domain, suggesting a role in stress signal perception and transduction (Liu et al., 2010; Zhu & Gao, 2025). In addition, several TLPs function as allergens in humans, derived primarily from fruits and pollen, including Mal d 2 (apple), Pru p 2 (peach), and Act d 2 (kiwi) (Rydzyńska et al., 2025).

Classification of TLPs

Thaumatin-like proteins (TLPs) display characteristic biochemical and structural features that are central to their functional roles in plant defense. These include their typical size, the presence of multiple conserved cysteine residues, and the formation of disulfide bonds, which

are critical for maintaining structural stability under stress conditions (Ren et al., 2022; Rydzynska et al., 2025). TLPs are defined by a conserved thaumatin family signature (PS00316) within their amino acid sequences, reflecting their evolutionary conservation and functional significance (Feng et al., 2024). Despite their widespread distribution across diverse plant species, TLPs share a remarkably similar three-dimensional structure, organized into three distinct domains (I, II, and III) and featuring a characteristic cleft between domains I and II (Liu et al., 2010). In TLPs with antifungal activity, this cleft is typically acidic due to specific conserved residues, distinguishing them from thaumatin proteins, where the corresponding cleft is basic. This structural variation is thought to underpin the functional differences between TLPs and thaumatin, particularly in mediating antifungal activity (Liu et al., 2010). Furthermore, the thaumatin family signature, denoted as G-x-x-C-x-T-x-D-C-x-x-C, is highly conserved across diverse TLP sequences, emphasizing their shared evolutionary origin and highlighting the structural basis for their functional versatility in plant defense (Feng et al., 2024; Liu et al., 2010).

Type Classification	Molecular Weight (MW)	Conserved Cysteine Residues	Disulfide Bonds	Occurrence
Large (L) Type	20–26 kDa	16	8	Most typical TLPs
Small (S) Type	16–17 kDa	10	5	Monocots, cereals, and conifers

Thaumatin-like Protein Family in Plants

The TLP family exhibits considerable variation in size and composition across different crop species, reflecting both evolutionary diversification and functional specialization. In wheat (*Triticum aestivum*), 129 TLP genes have been identified, which are organized into seven major phylogenetic clusters based on sequence similarity and evolutionary relationships, indicating extensive expansion within this species (Ren et al., 2022). In rice (*Oryza sativa*), approximately 31 TLP genes have been reported, representing a moderately sized yet functionally diverse family (Liu et al., 2010).

Soybean (*Glycine max*) also harbors multiple TLP genes, including well-characterized osmotin variants such as GmOLPa and GmOLPb, which are closely associated with responses to

abiotic and biotic stress (Feng et al., 2024). Similarly, in grapevine (*Vitis vinifera*), members of the TLP family, such as VvTLP-1, have been identified and linked to defense-related functions against pathogens (Liu et al., 2010). Collectively, these observations highlight the extensive diversity of the TLP gene family across crop species. This diversity suggests that TLPs play important and potentially specialized roles not only in plant defense but also in growth, development, and adaptation to environmental stresses, underscoring their significance in plant biology and crop improvement (Ren et al., 2022; Feng et al., 2024).

Molecular Mechanisms of Antifungal Action of TLPs

TLPs exert potent antifungal activity through multiple molecular mechanisms, primarily by targeting the fungal cell wall and plasma membrane, interfering with fungal signaling pathways, and acting synergistically with other defense proteins (Edreva, 2005).

Direct Cell Wall and Membrane Disruption

A central aspect of TLP-mediated defense involves the disruption of fungal cell integrity. TLPs, particularly those referred to as permatins, can directly permeabilize fungal plasma membranes, leading to plasmolysis, extensive cellular damage, and inhibition of fungal growth and development (Liu et al., 2010). The membrane-permeabilizing activity of TLPs, such as osmotin, is thought to result from electrostatic interactions with membrane components, which can induce conformational changes, collapse membrane potential, and promote pore formation, thereby compromising membrane integrity. For instance, tobacco osmotin has been shown to exert antifungal effects through direct membrane permeabilization (Zhu & Gao, 2025).

In addition to membrane targeting, TLPs can interact with β -1,3-glucans, key structural polysaccharides of fungal cell walls. This interaction often complements the activity of other pathogenesis-related proteins, such as β -1,3-glucanases (PR-2), enhancing cell wall degradation during hyphal growth (Liu et al., 2010). Some TLPs even exhibit intrinsic β -1,3-glucanase activity, enabling them to directly hydrolyze these polysaccharides and further compromise fungal structural integrity (Feng et al., 2024). The antifungal potency of TLPs thus arises from a combination of membrane permeabilization and cell wall degradation. By simultaneously targeting these two critical structural barriers, TLPs — often in coordination with other PR proteins such as chitinases and β -1,3-glucanases — effectively weaken fungal defenses and contribute to a robust plant immune response (Edreva, 2005).

Signaling Pathways Involving TLPs During Fungal Infection

TLPs are key components of plant innate immunity, linking pathogen perception with hormone-driven defense responses against fungal pathogens (**Fig. 1**). Upon fungal invasion, plants recognize pathogen-associated molecular patterns (PAMPs) through membrane-localized pattern recognition receptors (PRRs), which trigger early defense signaling events such as calcium (Ca^{2+}) influx, ROS production, and activation of mitogen-activated protein kinase (MAPK) cascades (Stroud et al., 2022). These early signaling events stimulate the biosynthesis and accumulation of defense-related hormones, particularly jasmonic acid (JA) and salicylic acid (SA), which are well-established regulators of antifungal immunity. Promoter analyses of TLP genes across diverse plant species, including cereals such as wheat, have revealed multiple JA- and SA-responsive cis-elements, consistent with strong induction under fungal stress. This indicates that hormone signaling acts as a major upstream regulator of PR-5 gene activation (Sharma et al., 2022).

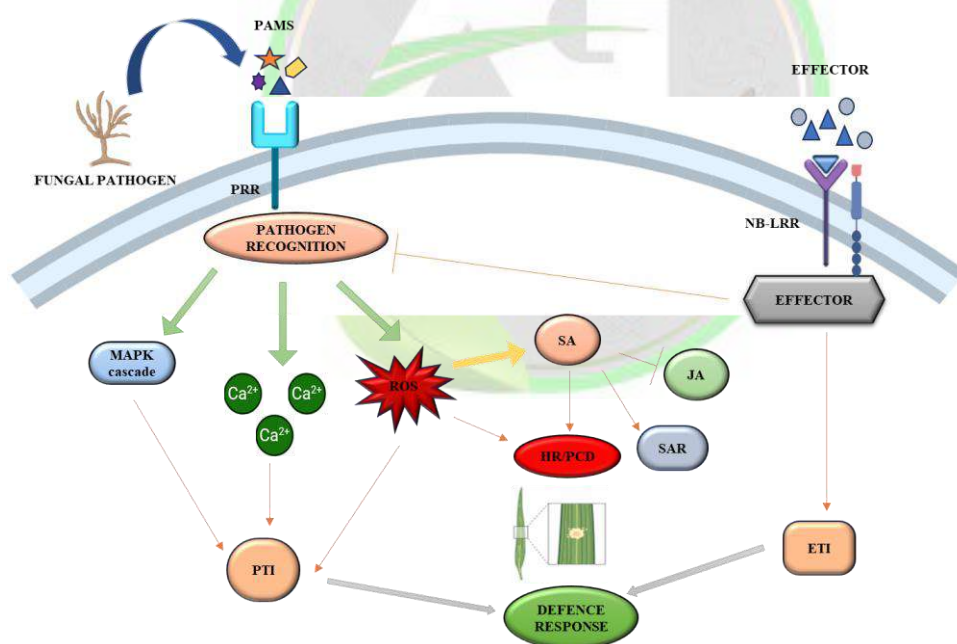


Fig. 1. Signalling Pathway involving TLPs during fungal infection. Fungal pathogen-associated molecules are recognized at the plasma membrane by **PRRs**, initiating **pathogen recognition** and early defense signals. These include activation of the **MAPK signaling cascade**, elevation of **cytosolic Ca^{2+} levels**, and rapid generation of **ROS**, which together contribute to **PTI**. Fungal pathogens may deliver **effectors** into host cells, which are sensed by

NB-LRR receptors, triggering ETI. Both lead to the activation of defense response.

Once expressed, TLP proteins primarily localize to the apoplast and cell wall. In these locations, they contribute to defense by permeabilizing or degrading fungal cell walls, reinforcing host cell wall integrity, and enhancing ROS-mediated antimicrobial responses (Sharma et al., 2022). Additionally, MAPK signaling and JA-mediated transcriptional networks coordinate the up-regulation of downstream antifungal genes, including other PR proteins, defensins, WRKY transcription factors, and regulators of oxidative bursts, establishing a multilayered and robust defense system (Stroud et al., 2022). Collectively, evidence from genome-wide analyses and functional studies demonstrates that TLPs act at the intersection of receptor-mediated pathogen recognition, hormone-responsive gene regulation, and cell-wall-associated defense. This integrated role **underlines the** conserved function of TLPs in antifungal signaling pathways across both monocot and dicot species

Synergistic and Constitutive Defense of TLP with Other PR Proteins

TLPs function as central components of both constitutive and inducible plant defenses, acting synergistically with multiple pathogenesis-related (PR) protein families during pathogen attack. In healthy plant tissues, several PR proteins including PR-2 (β -1,3-glucanases), PR-3/PR-4/PR-8/PR-11 (chitinases), PR-9 (peroxidases), and PR-10 (ribonucleases) are maintained at low basal levels as part of preformed defense mechanisms. Upon recognition of pathogen-derived elicitors and activation of SA and JA mediated signaling pathways, the abundance of these proteins rapidly increases (Dos Santos & Franco, 2023; Islam et al., 2023).

TLPs contribute to this early defense by permeabilizing fungal membranes and destabilizing cell walls, thereby enhancing the hydrolytic efficiency of PR-2 β -1,3-glucanases and PR-3/PR-4 chitinases. These enzymes act cooperatively to degrade β -glucans and chitin, the major structural components of fungal cell walls, and generate elicitor oligosaccharides that further amplify defense signaling (Dos Santos & Franco, 2023; Ebrahim et al., 2011). Concurrently, PR-9 peroxidases reinforce plant cell walls via lignification, while PR-10 ribonucleases contribute to localized hypersensitive cell death, demonstrating that TLPs operate within a larger, interdependent PR protein network that supports both local and systemic resistance (Islam et al., 2023).

Hormonal crosstalk further coordinates these synergistic defenses: SA-mediated pathways co-induce PR-1, PR-2, PR-5, PR-8, PR-9, and PR-10, whereas JA/ethylene (ET)

pathways activate PR-3, PR-4, and defensins (Islam et al., 2023; Stroud et al., 2022). Through their combined constitutive presence and tightly regulated inducible responses, TLPs and associated PR proteins provide a multilayered antifungal defense system that is broadly conserved across plant species.

Conclusion

TLPs represent a highly conserved and functionally versatile component of plant immunity, integrating structural stability with potent antifungal activity. Their diverse roles ranging from membrane permeabilization and β -1,3-glucan interaction to hormone-responsive regulation highlight their central position in defense signaling. TLPs act synergistically with multiple PR protein families, reinforcing both constitutive and inducible resistance through coordinated degradation of fungal cell walls and amplification of immune responses. Their broad distribution across plant species, evolutionary conservation, and integration with SA-, JA-, and MAPK-mediated pathways underscore their crucial contribution to strengthening plant resilience against fungal pathogens and enhancing overall stress tolerance.

References

- Dos Santos, C., & Franco, O. L. (2023). Pathogenesis-related proteins (PRs) with enzyme activity activating plant defense responses. *Plants*, 12(11), 2226. <https://doi.org/10.3390/plants12112226>
- Ebrahim, S., Kalidindi, U., & Singh, B. (2011). Pathogenesis related (PR) proteins in plant defense mechanism. *Science against Microbial Pathogens: Communicating Current Research and Technological Advances*, 2, 1043–1054.
- Feng, X., Zhang, L., Li, Y., & Chen, W. (2024). Structural and functional characterization of thaumatin-like proteins in plants. *Plant Molecular Biology*, 106(2), 145–160. <https://doi.org/10.1007/s11103-024-01567-2>
- Islam, Md. M., El-Sappah, A. H., Ali, H. M., Zandi, P., Huang, Q., Soaud, S. A., Alazizi, E. M. Y., Wafa, H. A., Hossain, Md. A., & Liang, Y. (2023). Pathogenesis-related proteins (PRs) countering environmental stress in plants: A review. *South African Journal of Botany*, 160, 414–427. <https://doi.org/10.1016/j.sajb.2023.07.003>
- Liu, J.-J., Sturrock, R., & Ekramoddoullah, A. K. M. (2010). The superfamily of thaumatin-like proteins: Its origin, evolution, and expression towards biological function. *Plant Cell Reports*, 29(5), 419–436. <https://doi.org/10.1007/s00299-010-0826-8>

- Ren, X., Jiang, Y., Li, Y., & Chen, X. (2022). Thaumatin-like proteins in plant defense and stress response. *Frontiers in Plant Science*, 13, 912296. <https://doi.org/10.3389/fpls.2022.912296>
- Rydzynska, Z., Malik, A., & Nowak, M. (2025). Plant thaumatin-like proteins: Molecular features and allergenic properties. *International Journal of Molecular Sciences*, 26(4), 2210. <https://doi.org/10.3390/ijms26042210>
- Sels, J., Mathys, J., De Coninck, B. M., Cammue, B. P., & De Bolle, M. F. (2008). Plant pathogenesis-related (PR) proteins: A focus on PR proteins with antifungal activity. *Plant Physiology and Biochemistry*, 46(11), 941–950. <https://doi.org/10.1016/j.plaphy.2008.06.011>
- Sharma, P., Singh, A., & Kumar, R. (2022). Hormone-mediated regulation of thaumatin-like proteins in plant defense. *Plant Science*, 319, 111232. <https://doi.org/10.1016/j.plantsci.2022.111232>
- Souza, T. P., Dias, R. O., & Silva-Filho, M. C. (2017). Defense-related proteins involved in sugarcane responses to biotic stress. *Genetics and Molecular Biology*, 40, 360–372. <https://doi.org/10.1590/1678-4685-GMB-2016-0057>
- Stroud, R., Thomas, J., & Walker, J. (2022). MAPK cascades and PR protein signaling in plant-fungal interactions. *Frontiers in Plant Science*, 13, 904512. <https://doi.org/10.3389/fpls.2022.904512>
- van Loon, L. C., Geraats, B. P., & Linthorst, H. J. (2006). Ethylene as a modulator of disease resistance in plants. *Trends in Plant Science*, 11(4), 184–191. <https://doi.org/10.1016/j.tplants.2006.02.005>
- Yan, L., Li, S., & Zhao, H. (2017). Structural insights into plant thaumatin-like proteins and their multifunctional roles. *Journal of Plant Biochemistry and Biotechnology*, 26(2), 145–156. <https://doi.org/10.1007/s13562-017-0398-3>
- Zhu, L., & Gao, F. (2025). Advances in PR5-like receptor kinases in plant stress signaling. *Plant Molecular Biology*, 108(1–2), 75–90. <https://doi.org/10.1007/s11103-024-01478-3>
- Zhu, L., & Schneider, R. (2024). Advances in plant immune responses and PR protein regulation. *Plant Molecular Biology*, 104(2), 101–117. <https://doi.org/10.1007/s11103-023-01456-8>

Volume: 05 Issue No: 12

AN OVERVIEW – PRODUCTION OF ACID LIME SEEDLINGS

Article ID: AG-VO5-I12-16**Bhanu murthy K C***

RHWEP students, IV year B.Sc (Hons) Horticulture, COH, Anantharajupeta,
Dr. YSRHU, Andhra Pradesh, India

*Corresponding Author Email ID: k.c.bhanumurthy1989@gmail.com

Introduction

We are a group of final-year students pursuing B.Sc. (Hons.) Horticulture from Dr. YSRHU - College of Horticulture, Anantharajupeta. As part of our academic curriculum, we have undertaken the Rural Horticultural Work Experience Programme (RHWEP) to gain practical exposure and hands-on experience in real-world rural farming situations. For this programme, our group of 11 students was allotted to Bhimavaram village of Chandragiri mandal, under the supervision of Regional Horticultural Research Station, Tirupati, Dr. YSRHU, Andhra Pradesh.

Area of Acid lime in Andhra Pradesh:

In Andhra Pradesh, acid lime is cultivating an area of 0.45 lakh ha with a production of 7.31 lakh MT and the productivity of 15 t per ha. Acid lime grows in the districts like SPSR Nellore, YSR Kadapa, Prakasam, Guntur, West Godavari, East Godavari, Chittoor and Anantapur districts.

Importance of Acid lime in Andhra Pradesh

Acid lime is important in Andhra Pradesh due to its significant contribution is to staes economy through commercial cultivation. Cultivation (particularly) in the semi-arid regions

Varieties in cultivation

1. Balaji
2. Petluru Pulusunimma
3. Vakula

Why only seedlings, why not budlings ?

Acid lime is polyembryonic i.e. more than one (multiple) embryos present in a single seed. Most of the embryos are nucellar i.e. develop from maternal tissue and one embryo is zygotic i.e. from fertilization.

In general, 2-3 seedlings produced from a seed, out of which one seedling developed from zygotic embryo, shows variation and other seedlings from nucellar embryos, which are genetically uniform like cloned plants. Hence, seedlings are preferred for propagation than budlings.

Type of embryos	Origin	Plant characteristics
Zygotic embryo	From fusion of Male and Female gamete	Shows variation
Nucellar embryo	From Maternal (mother plant) tissues	Identical to mother plant, true to type

Seedlings are preferred over budlings, as seedlings show more drought tolerance, slightly less in cost of production compared to budlings. And also budlings take more time for budwood preparation, budding at nursery and in some cases disease transfer also occurs from mother plants through budding.

Production of acid lime seedlings

Acid lime seedling production involves two types of nurseries i.e. primary and secondary nursery.

1. Primary Nursery

It can be done in two ways i.e. prostrate raising and raised bed method of raising.

a. Prostrate raising:

It involves usage of soil less media in prostrates of different cell types (50 cells, 98 cells etc.). It ensures better seed germination, faster root development, uniform seedling growth, offers easy transportation.

Media used in prostrates:

- Cocopeat (100%)** - Sterile, soft, light and excellent for germination, provides good aeration, ensures easy root penetration and rapid sprouting.
- Cocopeat + Perlite (3:1)** – 3 parts of cocopeat and 1 part perlite. Best mixture for nursery. Perlite also helps in aeration and improves drainage.



Seed sowing:

- Protrays filled with cocopeat (100%) and cocopeat + perlite (3:1)
- Sown the seed (already treated with thiram-2g/kg) i.e. one seed per cell at a depth of 1 cm.
- Kept the portrays under shadenet house
- Provided need based irrigation
- Germination occurred in 20-25 days



b. Raised bed method:

Prepared raised beds of size i.e. width of 1m, height of 15 cm and suitable length. Sown the seed in lines i.e. line sowing method. Covered the beds with organic mulch like paddy straw or any leaves and given regular irrigation, germination takes place in around 20-25 days.

2. Secondary Nursery

Once the seedlings become 45-50 days old with 2-3 pair of leaves, we transferred from primary nursery (portrays/raised beds) into secondary nursery i.e. polybags.

Polybags of 6 x 9 inches, filled with potting mixture (red soil, farm yard manure, chlorodust, bio fertilizers i.e. *Trichoderma viride*, *Pseudomonas* spp.). Regular and timely maintenance of seedlings with proper irrigation, balanced fertilizer application, effective pests and disease management is essential for 5-6 months until the seedlings are ready to sale. The price of each seedling is 50/-.



Volume: 05 Issue No: 12

HIDDEN DANGERS OF SEAFOOD ADULTERATION AND ITS IMPACT ON FOOD SAFETY

Article ID: AG-VO5-I12-17

**Balasubramanian Sivaraman^{*1}, Vijayakumar Renuka², Rajendran Shalini¹,
Ulaganathan Arisekar¹, Shanmugam Sundhar¹,**

¹Fish Quality Assurance and Management, Fisheries College and Research Institute, Tamil Nadu

Dr. J. Jayalalithaa Fisheries University, Thoothukudi, Tamil Nadu-628008

² Fish Processing Division, ICAR- Central Institute of Fisheries Technology, Willingdon Island,

Kochi, Kerala 682029, India

^{*}Corresponding Author Email ID: sivaraman@tnfu.ac.in

Introduction

Seafood is one of the widely preferred food commodity among the consumers all around the world because of their nutritional quality and delicacy. This high preference of seafood increases the demands every year. Moreover, elimination of numerous trade barriers between the countries pave the way for the increase of the seafood trade in international market. The high demand of seafood, continuous decline of fish resource in the nature as well as the trader's greedy on money, encourages the sellers to involve in seafood fraud. These seafood frauds usually done for economic gain consist variety of illegal activities, which often giving false, confusing, mislabelling as well as insufficient information to the consumers. Moreover, it affect the consumers not only in economically but also affect the consumer health. Hence the seafood supply has a long, non-transparent and complicated marketing channel, this seafood fraud can happened at any point of seafood trade. Due to the increasing complexity in seafood supply channel, it is difficult to point out the exact place and time where the seafood fraud happened. Seafood fraud consist several illegal activities viz., transshipment, overtreatment, mislabelling and species substitution.

Trans-shipment

Trans-shipment happens when a particular product exported from a country to another

through the third country instead of direct export. Although, in common business point of view trans-shipment is normally allowed, it is unlawful when trans-shipment can be carried out to avoid the tax and duties as well as other trade restrictions. A typical example is that if producer from Malaysia exports shrimps directly to US, they should pay an anti-dumping duty of 63%. Instead if he exports through a third country like Indonesia or Thailand, he can avoid this anti-dumping duty. Here, the trans-shipment is carried out to circumvent antidumping duty.

Over-treatment

Over-treatment of fish products are frequently done for several purposes such as gaining extra weight or reducing the core food material by increasing the coating material content. For instance, to increase the shrimp weight, processors use water-retaining chemicals such as sodium tripolyphosphate (STPP) or over-glazing with ice. Frozen seafood such as fillets, shrimps, crab claw and other different products are treated lightly with glaze water to dehydration which is caused by freezer burn. In general, surplus quantity of glaze water is purposely added in to the product to increase the product weight. Weight of this added glaze water should be excluded from the product weight which is mentioned in the product label.

To restrict the use of excess water as glaze in fishery products, USFDA reissued its 1991 guidance on 2009, should contain a warning to the seafood processing industries which explain the addition of excess water in the underweight products to falsify as a proper weight as mentioned in the label is an offense. Hence, STPP or other water-retaining chemicals treated seafood products should be clearly mentioned on the product label. Some food regulatory authorities advise to banned all the water retention chemicals which are used in fish and shellfish. Likewise in fish products, over-breading is another type of over-treatment, which may increase the product weight and consumers may paid excess amount for only the bread crumbs. To restrict these type of fraud, USFDA given a standard for breaded shrimp like products should contain at least 50% shrimp.

In another instance, Sashimi, a tuna product which is a popular food eaten as raw. Oxymyoglobin the compound responsible for bright red color which indicate the freshness of the tuna meat. Due to the long and improper storage condition oxymyoglobin will convert into metmyoglobin and it exhibit brown color. To mask the brown color and impaired quality of tuna, carbon monoxide (CO), the chemical react with the muscle pigments and form a stable carboxymyoglobin complex, has been applied in the meat to change the brown color into

desirable red color. This is another example of fish fraud by selling a stale fish as fresh by means of treating the tuna with a chemical.

Mislabelling

Any false and inappropriate information given for a particular products are comes under mislabeling. In case of fish and fishery products, human errors for fish species and origin identification may leads unintentional mislabeling in product preparation. However, mislabeling are intentionally practiced by the producers more often for economic gain. These types of illegal activities not only affect the consumer's health and wealth, but it also damages fishermen honesty and truthful seafood exporters who obey the rules. Moreover, mislabeling can also encourage the illegal or unregulated seafood fishing and export practice which affect the ecology of ocean by overfishing, fishing of endangered and depleting the stock by catching undersized fish species. Finally, mislabeling can leads to serious health issues by hiding the information about the presence of undeclared allergens, contaminants or toxins.

Species substitution

Among the different types of seafood fraud, species substitution is a serious threat in the seafood trade because of various reasons such as health, economic and ecological impact. Species substitution mainly done by adulterate low value fish species instead of high value species in the seafood supply chain to gain more money. A study conducted in U.S. revealed nearly 37% of fish and 13% of other seafood were mislabeled. Particularly 94 % of fish sold as red snapper (*Lutjanus campechanus*) in U.S. market was adulterated with other species (Marko *et al.*, 2004). There are different species substitution methods are done in the seafood supply chain such as substituting one species with other species, substituting same species of different geographical origin, substituting wild species with cultured species, substituting species with genetically modified species. Species substitution widely happened in worldwide are given in the table 1.

Table 1. Fish species substitution in worldwide markets

Species	Substituted By	Market
Cod (<i>Gadus morhua</i>)	Pacific cod (<i>Gadus macrocephalus</i>), Alaska Pollack (<i>Theragra chalcogramma</i>)	Japan,Europe, United States

Red snapper (<i>Lutjanus campechanus</i>)	Lane snapper (<i>L. synagris</i>) or crimson snapper (<i>L. erythropterus</i>)	United States
Grouper (<i>Ephinephelus</i> spp. and <i>Mycteroperca</i> spp.)	Nile perch (<i>Lates niloticus</i>) and wreck fish (<i>Polyprion americanus</i>)	Europe
Albacore tuna (<i>Thunnus alalunga</i>)	Skipjack tuna (<i>Katsuwonus pelamis</i>), yellowfin tuna (<i>T. albacares</i>)	Europe
Mediterranean horse mackerel (<i>Trachurus mediterraneus</i>)	Blue jack mackerel (<i>T. picturatus</i>)	Europe
European pilchard (<i>Sardina pilchardus</i>)	Other pilchard and sardinella (<i>Sardinops, Sarinella</i> spp.)	Europe
European hake (<i>Merluccius merluccius</i>)	Deep water hake (<i>M. paradoxus</i>), Chilean hake (<i>M. gayi</i>)	Europe
Sturgeon caviar (<i>Acipenser sturio</i>)	Siberian sturgeon caviar (<i>Acipenser baerii</i>)	Worldwide
Japanese mackerel (<i>Scomber japonicus</i>)	Atlantic mackerel (<i>Scomber scombrus</i>)	Japan
Surimi from Alaska Pollock (<i>Theragra chalcogramma</i>)	Cod (<i>Merluccius</i> spp.)	Europe
Blue mussel (<i>Mytilus galloprovincialis</i>)	Green mussel (<i>Perna</i> spp) and other mussel (<i>Aulacomya, Semimytilus</i> and <i>Choromytilus</i> spp.)	Europe
Bill fish species: <i>Makaira nigricans</i> (blue marlin), <i>M. indica</i> (black marlin), <i>Istiphorous platypterus</i> (sail fish), and <i>Tetrapturus audax</i> (striped marlin)	Sword fish (<i>Xiphias gladius</i>)	World wide

Health risks of species substitution

Although seafood products is generally promoted and recommended by nutritionists as a healthier protein alternative, several examples of mislabelling of fish and seafood may also put customer health at serious risk. More than 600 people in Hong Kong eventually admitted in the hospital after purchasing gempylotoxin contain escolar, and oilfish, which was actually mislabeled as Atlantic cod. The oily diarrhoea is caused by indigestible oil contained in these fish, which accumulates in the rectum before being expelled. Escolar is sometimes mislabeled as white tuna, super white tuna, rudderfish, butterfish, walu, cod, orange roughly and seabass. Seafood substitution also poses serious risks for people allergic to certain species. Fish and shellfish are some of the most common triggers for severe allergic reaction.

Mislabeling of pufferfish as “monk fish” and oilfish as ‘cod’ caused serious illness in Chicago. Pufferfish contains tetrodotoxin (TTX), which is a heat-stable neurotoxin that blocks sodium conductance and neuronal transmission in skeletal muscle leading to weakness or paralysis and potentially death, if ingested in sufficient quantities. Another hazard that arises from mislabeling seafood is the possibility of unknowingly serving fish from a region that has been flagged for a health risk. For example, if an area of the water is closed because of Ciguatera and snapper is caught in that area and then labeled as a species not typically from that area that is a health issue. Ciguatera is an important form of human poisoning. The disease is characterized by gastrointestinal, neurological and cardiovascular disturbances. In cases of severe toxicity, paralysis, coma and death may occur. Another health problem is created when fish containing histidine are mislabeled. Histidine can be converted to histamine over time by enzymes released in the fish due to the action of spoilage bacteria. High levels of histamine, an allergen, can cause illness when ingested by humans. If a histidine rich fish, such as tuna or swordfish, is labeled as a fish that doesn’t carry histidine, such as grouper. Some fish, such as tilefish, contain high levels of mercury, and women who are pregnant or breast feeding are advised to avoid these fish. Tilefish are commonly mislabeled as halibut and red snapper. Substitutions of these species for others can also pose a health risk.

Financial losses

Mislabelling of seafood products cause financial losses mainly for customers, if they are manipulated to pay higher prices for substituted products of a lower value. The industry of domestically farm-raised catfish in America suffered from the import of Vietnamese frozen fish

fillets sold as catfish, but produced from a different species commonly known as basa or tra. At a certain point, the total import of these pangasius species from Vietnam captured at least 20% of the American catfish market and reached the scale when local fish farming become non-profitable.

Ecological losses

The increased awareness of sustainable and ethical fishing is more often observed among customers in developed countries, e.g., Swedish Organizations and consumers have boycotted Baltic cod because of perceived overfishing and farmed salmons have been boycotted by Canadian “Farmed and Dangerous” groups. These efforts are pointless, if mislabeling of seafood products occurs and Baltic cods and farmed salmons are still sold under different labels. In 1996, stocks of red snapper considered to be one of the most economically important fish in the Gulf of Mexico were declared grossly overfished and the incidents of mislabeling probably affected the accuracy of fishery resource management data.

Authentication methods

A variety of DNA based methods such as PCR-RFLP, AFLP, RAPD, SNP and microsatellites offer a promising alternative for reliable species differentiation even in heated food samples, since the thermostability of DNA is much higher than that of proteins. To date, PCR-RFLP methods were widely using for seafood authentication because of their reliability, simplicity and cost effective advantages. Sumathi et al. (2015) have developed PCR-RFLP markers for identification of five species of raw and processed groupers belonging to the genus, *Epinephelus*. Nagalakshmi et al. (2016) conducted a study to find out the level of seafood mislabeling prevailing in India using DNA barcoding and the study revealed 22% of seafood mislabeling prevailing in Indian domestic market. Several works have been developed molecular markers on authentication of commercially important shrimp species (Wilwet et al., 2018) and snappers (Sivaraman et al., 2018 & 2019a). Recently SSCP markers were developed by Sivaraman et al. (2019b) for the rapid identification of high valued exportable species from the genus *Lutjanus*.

Conclusion

Consumers have the right to know more about the seafood they eat and have confidence that the information they receive is accurate. Seafood fraud not only cheats consumers, but it can also have harmful effects on human health and our ocean ecosystems. Ensuring that the seafood

sold assafe, legal and honestly labeled should not be a luxury, but a necessity. Seafood traceability, or tracking fish from boat to plate, would significantly reduce seafood fraud, while providing consumers with more information about what they are eating. Traceability allows officials and those in the supply chain to know more about where the fish came from, while making it harder to mislabel and misrepresent seafood. Labeling requirements should be included in any traceability system adopted. Seafood labels need to include critical information such as when, where and how a fish was caught, what species it is, whether it was farmed or previously frozen and if any additives have been used during processing. By implementing full traceability of all seafood sold in the markets, consumers will be protected from seafood fraud, and illegally caught fish will be kept out of the markets.

Reference

- Jacquet, J. L., & Pauly, D. (2008). Trade secrets: renaming and mislabeling of seafood. *Marine policy*, 32(3), 309-318.
- Marko, P. B., Lee, S. C., Rice, A. M., Gramling, J. M., Fitzhenry, T. M., McAlister, J. S., Harper, G. R., & Moran, A. L. (2004). Fisheries: mislabelling of a depleted reef fish. *Nature*, 430, 309-310.
- Nagalakshmi, K., Annam, P. K., Venkateshwarlu, G., Pathakota, G. B., & Lakra, W. S. (2016). Mislabeling in Indian seafood: An investigation using DNA barcoding. *Food control*, 59, 196-200.
- Sivaraman, B., Jeyasekaran, G., Shakila, R. J., Aanand, S., & Sukumar, D. (2019b). Authentication of nine snapper species by single-strand conformation polymorphism (SSCP) and forensically informative nucleotide sequencing (FINS) methods. *Food Control*, 99, 124-130.
- Sivaraman, B., Jeyasekaran, G., Shakila, R. J., Alamelu, V., Wilwet, L., Aanand, S., & Sukumar, D. (2018). PCR-RFLP for authentication of different species of processed snappers using mitochondrial D-loop region by single enzyme. *Food Control*, 90, 58-65.
- Sivaraman, B., Jeyasekaran, G., Shakila, R. J., Wilwet, L., Alamelu, V., Aanand, S., & Sukumar, D. (2019a). Molecular identification of *Lutjanus* species by PCR-RFLP analysis of mitochondrial 12S rRNA region. *Journal of Food Composition and Analysis*, 84, 103329.



- Sumathi, G., Jeyasekaran, G., Shakila, R. J., Sivaraman, B., Arunkumar, G., Manimaran, U., & Sukumar, D. (2015). Molecular identification of grouper species using PCR-RFLP technique. *Food Control*, 51, 300-306.
- Wilwet, L., Jeyasekaran, G., Shakila, R. J., Sivaraman, B., & Padmavathy, P. (2018). A single enzyme PCR-RFLP protocol targeting 16S rRNA/tRNA^{Val} region to authenticate four commercially important shrimp species in India. *Food chemistry*, 239, 369-376



HEALTH BENEFITS OF GARDENING

Article ID: AG-VO5-I12-18**M.Marimuthu***

Krishi Vigyan Kendra, TNAU, Sirugamani, Trichy- 639 115, Tamil Nadu, India

*Corresponding Author Email ID: mmarimuthu@tnau.ac.in

Introduction

Gardening isn't just about planting pretty flowers or growing delicious vegetables - it's a powerful activity that can do wonders for your health! Whether you have a huge backyard or just a small balcony, getting your hands muddy in the soil can bring numerous benefits to your well-being. Let's explore why gardening is good for your health and why you should consider taking up this enjoyable and rewarding hobby.

1. Improves Physical Health:

One of the main advantages of gardening is that it is good for your overall good physical health. Gardening is a form of exercise that involves activities like digging, planting, weeding, and watering, which can help improve your strength, flexibility, and endurance. Regular gardening can be a fun and enjoyable way to stay active and maintain a healthy lifestyle.

2. Stress Reduction:

Life can be stressful but gardening can be a great way to unwind and relax. Spending time outdoors, surrounded by nature, can help lower stress levels and promote a sense of calm. The act of tending to plants and watching them grow can be therapeutic, allowing your mind to focus on the present moment and forget about worries and anxieties.

3. Better Sleep:

Spending time outdoors and engaging in physical activity can help regulate your body's internal clock. Exposure to natural sunlight during the day and spending time in the fresh air can improve sleep quality, leading to a more restful and rejuvenating slumber at night.

4. Mood Booster:

Have you ever felt happier after spending time in a garden? Well, there's science behind it! Gardening encourages the release of endorphins, also known as happy hormones," which can lift your spirits and improve your mood. The sense of accomplishment from seeing your plants grow and bloom can bring a deep sense of satisfaction and joy.

5. Nutritious and Fresh Rewards:

If you grow your vegetables and fruits, you can enjoy the added benefit of harvesting your produce. Home grown fruits and vegetables are often fresh and more nutritious than store-bought ones. Plus, the act of growing your food can encourage you to incorporate healthier choices in your diet.

6. Enhances Mental Health:

Another health benefit of Gardening is that it acts like a meditation activity for the mind. It can reduce symptoms of depression and anxiety and improve overall mental well-being. Being surrounded by greenery and fresh air can boost cognitive function and increase focus, making you feel more energized and mentally sharp.

7. Increases social connections:

Gardening can be a social activity that allows you to connect with others who share your interests. It can also be a great way to give back to your community by sharing your produce with friends and neighbors.

8. Established a Connection with Nature:

In modern times and busy fast-paced life, people often don't make time to spend time with nature. Gardening allows you to reconnect with the natural world. This connection can lead to increased environmental awareness and a desire to protect and preserve our planet.

Gardening is more than just a pastime. It's a health-boosting activity with innumerable benefits for your mind, body and soul. From reducing stress and promoting physical exercise to enhancing your mental well-being of your life. So roll up your sleeves and start cultivating your little green heaven at your home for a peaceful and healthy inner self.

GHERKIN- AN EXPORT VALUED UNDERUTILIZED VEGETABLE CROP

Article ID: AG-VO5-I12-19

¹Marichamy, M. S., ¹V. Kanthaswamy, ^{1*}V. Krishnan, ²N. Bavya and ³B. Bavithra¹Faculty, ²PG Scholar & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Gherkin, botanically called *Cucumis sativus* var. *angaria*, ($2n = 24$), belonging to Cucurbitaceae family, commonly known as maroon cucumber, West Indian Gherkin, Maxixe, Burr gherkin, Cackrey, and West Indian gourd. Gherkin is a vine that is indigenous to Africa, but has become naturalized in the New World, and is cultivated in many places. It is similar and related to the common cucumber (*C. sativus*) and its cultivars are known as Gherkins.

ORIGIN AND DISTRIBUTION

Gherkin (*Cucumis anguria*) belongs to family Cucurbitaceae which comprises of in the range of 118 genera and 825 species. Members of this family are spread mainly in tropical and subtropical regions of the world even though they have an African origin. Gherkins and commercial cucumbers belong to the same species (*Cucumis*), but are from different cultivar groups. Most cucumbers are consumed in fresh forms, while gherkins have a great popularity among the world as fermented pickles.

BOTANICAL DESCRIPTION

Gherkin is an annual herbaceous monoecious plant with trailing or scandent grooved stems 2–3 m long bearing bristly hairs. Tendrils solitary, simple tendrils 3–6 cm long. Leaves simple, alternate, stipules absent, petiole 6–13 cm long, shallowly to deeply palmately lobed with 3–5 lobes, hairy on both surfaces. Flowers unisexual, regular, pentamerous, sepal triangular, narrow, 1–3 mm long, petals united at base, 4–8 mm long, yellow; male flowers borne in 2- to 10-flowered fascicles, pedicels 0.5–3 cm long, stamens 3; female flowers solitary, pedicel 2–10

cm long, ovary ellipsoid, inferior, 7–9 mm long, softly spiny, stigma 3-lobed. Fruit an ellipsoid to sub-globose berry, 3–4.5 x 2–3.5 cm, stalk 2.5–21 cm long, bearing thin, soft spines, green ripening to yellow, many seeded. The inner flesh is pallid to green. Seeds ellipsoid, 5–6 mm long, compressed with rounded margins and smooth.



NUTRITIONAL COMPOSITION (ON FRESH WEIGHT (g/100 g))

CONSTITUENTS	AMOUNT
Moisture	96.30 %
Carbohydrate	2.50 g
Vitamin A	105 IU
Protein	0.40 g
Fat	0.10 g
Energy	13 Kcal

RELATED SPECIES OF GHERKIN

1. *Cucumis melo* var. *conomon* (Oriental Pickling Melon): This variety, known as the Oriental pickling melon or Makuwa, is common in East Asia. The fruits are long, cylindrical, and typically used for pickling. The skin is smooth, and the flesh is firm, making it suitable for pickling and preserving. Primarily used for pickling in East Asian cuisine. It can also be consumed fresh or with salads.

2. *Cucumis melo* var. *chate* (Kachri or Small Melon): Kachri is a smaller, rounder variety of long melon, commonly found in the arid regions of India. It has a rough skin and a bitter to sweet taste. The fruit is often used in traditional dishes for its unique flavour. Widely used in Rajasthani cuisine, particularly in chutneys, pickles and as a spice.

3. *Cucumis melo* var. *inodorus* (Winter Melon or Honeydew): Winter melon includes varieties like honeydew, which are larger and rounder but can also include elongated forms. These melons have a smooth, waxy rind and sweet, juicy flesh. Used as consumed fresh, in fruit salads, or as a dessert. Some elongated varieties are also pickled or used in cooking.

4. *Cucumis melo* var. *cantalupensis* (Cantaloupe): Cantaloupe or muskmelon is another relative of the long melon, although it is typically round and sweet. Some varieties, however, can be slightly elongated. Consumed fresh, in fruit salads, or as a dessert. The aromatic flesh is sweet and often eaten as a snack.

FLORAL BIOLOGY

Gherkin plants are monoecious and both male and female flowers have five yellow petals, which are fused at the base. The flowers are typically small, around 1-2 cm in diameter, and have a slightly hairy texture. The anthesis of gherkin flowers generally occurs early in the morning, with the flowers opening around sunrise. The peak activity for pollination is typically between 5:00 and 9:00 AM.

CLIMATE AND SOIL

The Gherkin plant is frost-sensitive and it develops physiological disorders (e.g. stunting) at a night temperature of below 5°C. Gherkin plant germinates and grows at a minimum temperature of approximately 12°C and opens its flowers from 15°C. Well-drained sandy loam with a pH range of 6.0 to 6.8 is optimum for Gherkin farming. Heat-absorbing, humus-rich soil with good water holding capacity and good structure is normally suited for cultivating gherkins. These contain humic loamy sand and sandy loam as well as black soil. The pH-optimum level lies in the range of pH 5.8 to 7.

COMMERCIAL VARIETIES

1. Rijk Zwaan: High yielding variety with. Outstanding quality, regular fruit shape and good consistency make possible high quality export production. The safety of the production is assured by the good regeneration potential of this variety. The open plant habit makes possible the harvest at the desired fruit sizes.

LAND PREPARATION

Land is levelled by a tractor or bulldozer as per the requirement, soil type and gradient. Raised beds of 120 cm width at an interval of 30 cm should be done and the laterals should be placed at the centre of each bed. Before cultivation, 25 t/ha of Farm Yard Manure should be applied. The ridges and furrows should be made one metre apart.

SOWING AND PLANTING

A good weather should be chosen for direct sowing. Soil insecticides should be used before sowing. A shallow bed (3-5 cm) should be created and kept wet. Seeds should be sown on the wet soil and covered with thin layer of soil. The soil should be irrigated again in case of drying out. The seeds should be sown at 30 cm spacing on sides of the ridges with 2 seeds per hill after treating with *Trichoderma viride* @ 4 g or *Pseudomonas* @ 10 g or carbendazim @ 2 g/kg of seeds. After cultivation, the plants should be earthed up 25 days after sowing. Support should be provided to plants as and when vines start trailing.

MANURES AND FERTILIZERS

Fertilization is one of the main important determining factors of intensive Gherkin production. If the amount of nutrients is insufficient, yields and income will be lower, also the plants that have a weakened condition are more susceptible to diseases. If the Gherkin plants are wastefully over-fertilized, the costs will quickly increase and the income of the season will stay below the expectations. The concentrated soil solution may cause the burning down of the capillary roots and the plant is not being able to take up the nutrients from the soil. At three and five weeks after sowing, N - 150 kg, P - 75 kg and K - 100 kg/ha should be applied in 3 equal splits as basal fertilizer. The recommended dose of fertilizers viz., 150:75:100 Kg NPK / hectare should be fertigated on every third day after sowing.

WEEDING AND IRRIGATION

The inter-rows can be sealed with soil-applied herbicide film and in case of torrential rain, there is the danger of illuviation. As soon as weeds have emerged hand-high and the fleece is opened, weeds in the plant sowing holes have to be pulled out by hand. Between the planting rows, hoeing can be done mechanically or a total herbicide can be applied if a spray screen is used. In the latter case, the fleece should not be closed earlier than half a day or a day later. Irrigation has to be done once or twice per summer day. Gherkin plants evaporate a lot of moisture and lack of irrigation leads to abortion of young fruits and hollow spaces in large fruits.

Drip irrigation system with main and sub-main pipes should be installed and the inline lateral tubes should be placed at an interval of 1.5m. The drippers in lateral tubes should be placed at an interval of 60 cm and 50 cm spacing with 4 and 3.5 litres per hour capacities respectively.

SPECIAL PRACTICES

1. Staking: The crop requires staking, being a creeper, and if not staked, the fruits will be formed on the ground. Staking is done between 16 to 20 days after sowing. Staking is done using wooden stakes held serially by Galvanized Iron (GI) wire and the vines are trained to grow along the jute thread tied on to the GI wires connecting the top and bottom GI wires. Usually, stakes are of 2.4 m length and 5 cm diameter to support the weight of the crop till the end. They are grouted 30 cm below the ground level at a distance of 3.5 meters. Stakes at the end of the row are strengthened with good gauge of GI wire (10 to 12 gauge for border and 16 to 18 gauge along the rows) to hold the crop firmly. Staking, besides supporting the plant to stand straight, facilitates ventilation, cultural operations and quick harvest of fruits. This ensures sunlight reaching every fruit, thereby avoiding bleaching.

HARVESTING

Gherkins are usually harvested when they have a vibrant green colour. The skin should be bright and glossy, indicating that the fruit is at the ideal stage for pickling. The fruits must be harvested by retaining the stalk on the plant. Harvested fruits should be collected under shade. The flower head has to be removed from fruit and water sprinkling on harvested fruits should not be done at any stage. The surface moisture must be dried by proper ventilation. The crop is ready for harvest in 30 to 35 days. The price of the product is decided by the stage of maturity. Only the tender immature Gherkin fruits are highly suited for processing. Smallest fruit (stage 1) which will weigh approximately 4.0 g (250 fruits per kg) will fetch the maximum price. Gherkin yields 10-12 t/ha in 90 days.

PEST MANAGEMENT

1. Spinning mites: White-silver spots appear on the leaves, often confused with micro elements' deficiency. On the backside of the leaf 0.3-0.8 mm small insects can be noticed near the veins. If their number increases cobweb-like coverage appears on the under surface. To control mites it's necessary to notice the early symptoms and use acaricides. Warm and dry weather always brings about the spread of the mites.

DISEASES MANAGEMENT

1. Angular leaf spot (*Pseudomonas syringae* pv. *lachrymans*): Small yellow-brown (3-5 mm) angular spots appear on the leaves, the under surface is shiny green, later dries towards brown and finally the center of the spots fall out and the leaf appears perforated. Control by bactericide (Kasugamicin) and copper fungicides (Champion, Cuproxate) and the infected leaves should be removed.

2. Downy mildew (*Pseudoperonospora cubensis*): The leaves become mottled by 5-8 mm angular yellow spots which never fall out of the leaf. On the under surface of the spots downy grey coverage develops. For the infection at least 4 hours of moisture of the leaves is necessary and temperatures should be at least 16-17°C. Symptoms appear 4-5 days after the infection. To control this disease the use of contact (Bravo, Champion, Orthophaltan) and systemic (Aliette, Curzate, Acrobat, Previcur, Mikal) fungicides is necessary. It is important to use the systemic materials in blocks (2-3 treatments) for a proper control.

PHYSIOLOGICAL DISORDER AND CONTROL MEASURES

1. Blossom End Rot: Sunken, dark, and water-soaked lesions at the blossom end of the fruit. Caused by calcium deficiency, inconsistent watering, or poor calcium uptake. To manage maintain consistent moisture ensure even soil moisture by watering regularly and avoiding drought or waterlogging. Use calcium supplements or calcium-rich fertilizers if soil tests indicate a deficiency. Maintain soil pH between 6.0 and 6.8 for optimal nutrient uptake.

2. Pillow disorder: It is a fruit disorder of processing cucumber due to low calcium level in the tissue. In this disorder, an abnormal white styro-foam like porous textured tissue is formed in the mesocarp of the fleshy harvested fruits. Vascular tissue with some pillow areas may collapse and become necrotic. Application of calcium adequately control this disorder.

3. Hollow Heart: Cracks in internal watermelon fruit flesh can occur due to accelerated growth in response to ideal growing conditions. There is a genetic component to this disorder, but growing conditions can account for much of the variation observed. It appears to be associated with conditions that result in poor pollination followed by rapid fruit growing conditions. Avoid watermelon varieties with a tendency to exhibit hollow heart. Implement best practices for irrigation and fertilization programs.

POST HARVEST MANAGEMENT PRATICES

1. Fruit Storage: Harvested fruits are promptly carried to the shed, which serves as a

temporary storage facility following staking. Farmers build rectangular barns with a level floor surface on the top and three sides. Fertilizer bags should not be used to build the shed. To prevent fruit contamination, the shed is not used to store other products such as insecticides, fertilizer, or sprayers. Fruits are laid on a clean tarpaulin on the floor inside the shed to improve ventilation and shield them from direct sunshine or rain. Fruits are visually inspected for flaws before being handed over to processing companies. After screening, the fruits are placed in large bamboo baskets, netting bags, or gunny bags until the pickup vehicle arrives.

2. Grading: Collection of fresh fruits from the field Grading as per fruit count Washing the graded fruits Preparation of 14 percent brine solution Filling the graded gherkins in barrel Filling barrels with gherkin with brine solution Adding salt on daily basis to maintain 14 per cent brine. Keeping the barrels for 30 days for fermentation and osmosis Quality inspection Weighing 175 kg and pack in 240 liter barrels with brine 4 Closing barrels with lid for shipment. Put ingredients like chopped onion, mustard seed, etc as per recipe in the washed bottles moving on conveyor Filling gherkins in the holes moving on conveyor Filling the bottles with the packing medium as per recipe Weighing Vacuum closing of bottles with lid 1 Cooking the bottled gherkin (Autoclave at 92°C for 18 minutes) Cooling (Dipping the Autoclave water for 12 minutes)

3. Labelling and Packing: The gherkin packed both in bulk as well as in consumer packs (bottled pickle). “Bulk packing is made in Food Grade High Molecular weight High Density Polyethylene (HMHDPE) barrels of usually 220/240 litre capacity (net drained weight of fruits 150 to ISO kg per barrel) or as per customer specifications. As mentioned earlier, with the increase in wage rates in the European Union member countries, the importers prefer gherkins bottled in consumer packs for exports rather than bulk. The EOUs harvest up bottling units, which can bottle 3000 bottles per hour. Consumer packs are usually packed in glass jars of size 500, 650 or 750 ml. As a general practice, each importer gives the EOU the recipe for the pickle, bottles, vinegar and labels for the consumer pack required by them.

4. Marketing: The gherkin industry in India is primarily concentrated in three southern states of Karnataka, Andhra Pradesh and Tamil Nadu. Marketing is promoted as a new era Agri-export system in these states.

Volume: 05 Issue No: 12

THE COMPLETE GUIDE TO ORGANIC INPUTS: BUILDING SOIL HEALTH NATURALLY

(A Comprehensive Resource for Sustainable Farming in Tamil Nadu)

Article ID: AG-VO5-I12-20**¹P. Jaisridhar and ²S. Esvaran**¹ICAR – Krishi Vigyan Kendra, TNAU, The Nilgiris, Tamil Nadu, India²UG Scholar, Horticultural College & Research Institute, TNAU, Coimbatore

*Corresponding Author Email ID: jaisridhar@tnau.ac.in

Introduction

In an era where chemical-intensive agriculture has shown its limitations—depleted soils, declining yields, and environmental degradation—organic farming emerges not just as an alternative, but as a necessity. For farmers in Tamil Nadu, particularly in regions like the Nilgiris where ecological sensitivity meets agricultural productivity, understanding and implementing organic inputs has become crucial for sustainable livelihoods.

This comprehensive guide presents a systematic approach to organic farming inputs, covering everything from traditional manures to modern bio-fertilizers, pest management solutions, and soil conditioners. Whether you're a smallholder farmer in the hills or managing extensive plantations in the plains, this knowledge base will help you transition to or enhance your organic farming practices.

Part 1: Foundation of Soil Fertility - Organic Manures

Understanding Organic Manures

Organic manures form the backbone of soil health, providing not just nutrients but also improving soil structure, water retention, and microbial activity. Unlike chemical fertilizers that offer quick fixes, organic manures work slowly and steadily, building long-term soil fertility.

1. Farm Yard Manure (FYM): The Gold Standard

What It Is: FYM is decomposed cow dung mixed with urine and bedding materials—the cornerstone of organic farming that farmers have trusted for centuries.

Nutrient Profile:

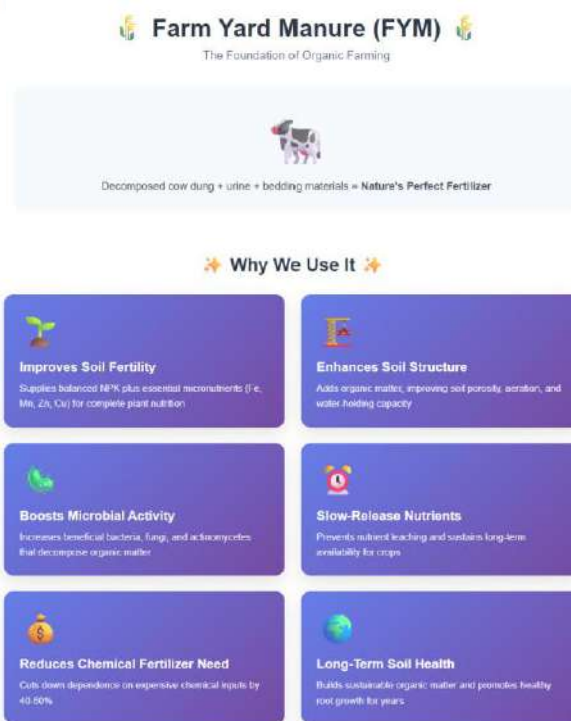
- Nitrogen: 0.5%
- Phosphorus: 0.2%
- Potassium: 0.5%
- Organic Carbon: 20-25%
- Rich in micronutrients (Fe, Mn, Zn, Cu)

Application Guidelines:

Crop Type	Quantity	Timing
Field crops	10-12 tons/acre	15-20 days before sowing
Vegetables	10-15 tons/acre	Before transplanting
Orchards	20-25 kg per tree	Once a year (pre-monsoon)

Critical Success Factors:

- Use only well-decomposed FYM (raw FYM harbors pathogens and weed seeds)
- Mix into top 15-20 cm soil
- Cover heap during storage to prevent nutrient loss from rain
- Maintain 50-60% moisture during decomposition



Farm Yard Manure (FYM)
The Foundation of Organic Farming

Decomposed cow dung + urine + bedding materials = Nature's Perfect Fertilizer

Why We Use It

- Improves Soil Fertility**
Supplies balanced NPK plus essential micronutrients (i.e. Mn, Zn, Cu) for complete plant nutrition
- Enhances Soil Structure**
Adds organic matter, improving soil porosity, aeration, and water holding capacity
- Boosts Microbial Activity**
Increases beneficial bacteria, fungi, and actinomycetes that decompose organic matter
- Slow-Release Nutrients**
Prevents nutrient leaching and sustains long-term availability for crops
- Reduces Chemical Fertilizer Need**
Cuts down dependence on expensive chemical inputs by 40-50%
- Long-Term Soil Health**
Builds sustainable organic matter and promotes healthy root growth for years

2. Compost: Farm Waste to Fertility

Compost transforms your farm waste into valuable soil amendment through controlled decomposition.

Preparation Method:

1. Collect farm waste, crop residues, kitchen waste, dry leaves
2. Layer: dry biomass → green biomass → cow dung slurry
3. Maintain 50-60% moisture
4. Turn heap every 15-20 days for aeration
5. Ready in 45-90 days when dark, loose, and earthy

Nutrient Content:

- Nitrogen: 0.8-1.2%
- Phosphorus: 0.3-0.6%
- Potassium: 0.8-1.0%
- Organic carbon: 15-25%

Application Rates:

Crop Type	Quantity	Timing
Field crops	6-8 tons/acre	10-15 days before sowing
Vegetables	8-10 tons/acre	Before planting/transplanting
Orchards	10-15 kg per tree	Once a year, before monsoon
Small area (1680 sq.m)	3-4 tons	2 weeks before sowing

3. Vermicompost: Nature's Black Gold

Earthworms transform organic waste into nutrient-rich castings with remarkable efficiency.

Production Process:

1. Pre-decompose organic waste for 18-21 days
2. Spread in vermibeds (15-20 cm thick)
3. Introduce earthworms (1-2 kg per ton of waste)
4. Maintain 60-70% moisture
5. Keep temperature at 25-30°C
6. Ready in 45-60 days

Superior Nutrient Profile:

- Nitrogen: 1.5-2.0%
- Phosphorus: 0.9-1.2%
- Potassium: 1.0-1.5%
- Contains plant growth hormones (IAA, GA, cytokinin)
- Very high microbial count

Application Guidelines:

Crop Type	Quantity	Special Notes
Field crops	1-2 tons/acre	Before sowing
Vegetables	2-3 tons/acre	Before transplanting
Orchards	5-10 kg per tree	Once or twice per year
Nursery	10-20% of potting mix	During sowing
Small area (1680 sq.m)	400-700 kg	1-2 weeks before planting

4. Green Manure: Living Fertility

Green manuring involves growing crops specifically to be ploughed back into the soil.

Common Green Manure Crops:

- Sunhemp (Daincha)
- Cowpea
- Sesbania
- Pillipesara

Process:

1. Sow seeds at recommended spacing
2. Allow 45-60 days growth
3. Incorporate entire biomass when tender
4. Light irrigation after incorporation

Seed Rates and Benefits:

Crop	Seed Rate	Biomass Added	Key Benefit
Sunhemp	20-25 kg/acre	4-6 tons/acre	High N fixation
Daincha	20-25 kg/acre	4-6 tons/acre	Fast growing

Crop	Seed Rate	Biomass Added	Key Benefit
Cowpea	15-20 kg/acre	3-5 tons/acre	Dual purpose

Nitrogen Contribution: 2-3% in biomass, equivalent to 40-60 kg N/acre

Part 2: Concentrated Nutrition - Oil Cakes

Oil cakes are byproducts of oil extraction that serve dual purposes: nutrition and pest control.

Comparative Analysis of Oil Cakes:

Oil Cake	N (%)	P (%)	K (%)	Special Property	Application Rate
Groundnut	7-8	1-1.5	1-1.5	Highest N content	100-150 kg/acre
Castor	4-4.5	1-1.5	1-1.5	Strong pest repellent	150-250 kg/acre
Pongamia	3.5-4	0.8-1	1-1.5	Nematicide	150-200 kg/acre
Neem	2-3	0.5-1	1-1.5	Broad pest control	100-200 kg/acre

Oil Cakes: Dual-Purpose Organic Inputs

Nutrition + Pest Control in One Package

Why Use Oil Cakes?

Oil cakes are byproducts of oil extraction that serve **TWO** purposes:

- 1. Slow-release nutrition for crops
- 2. Natural pest and disease control

Single Input = Double benefit = Maximum efficiency!

Quick Comparison Chart

Oil Cake	Nitrogen	Phosphorus	Potassium	Special Power	Application
Groundnut	7-8% ★★★★★	1-1.5%	1-1.5%	Highest N content	100-150 kg/acre
Castor	4-4.5% ★★★	1-1.5%	1-1.5%	Strong pest repellent	150-250 kg/acre
Pongamia	3.5-4% ★★	0.8-1%	1-1.5%	Nematicide	150-200 kg/acre
Neem	2-3% ★	0.5-1%	1-1.5%	Broad pest control	100-200 kg/acre

Groundnut Cake

Nitrogen (N)	7-8%
Phosphorus (P)	1-1.5%
Potassium (K)	1-1.5%

RICHEST NATURAL NITROGEN SOURCE

- ✓ Supports vigorous vegetative growth
- ✓ Improves flowering and fruiting
- ✓ Increases organic carbon in soil
- ✓ Boosts soil microbial life
- ✓ Sustained slow nutrient release

Application Rate:
Field crops: 100-150 kg/acre
Vegetables: 150-200 kg/acre
Orchards: 0.5-1 kg/tree

Castor Cake

Nitrogen (N)	4-4.5%
Phosphorus (P)	1-1.5%
Potassium (K)	1-1.5%

STRONG PEST REPELLENT

- ✓ Promotes strong vegetative growth
- ✓ Acts as natural pest deterrent
- ✓ Controls nematodes and soil insects
- ✓ Enhances microbial activity
- ✓ Excellent for banana, turmeric, sugarcane

Application Rate:
Field crops: 150-250 kg/acre
Vegetables: 200-300 kg/acre
Orchards: 1-2 kg/tree
Apply 10-15 days before planting

Pongamia/Karanja Cake	Neem Cake
Nitrogen (N) 3.5-4%	Nitrogen (N) 2-3%
Phosphorus (P) 0.8-1%	Phosphorus (P) 0.5-1%
Potassium (K) 1-1.5%	Potassium (K) 1-1.5%
POWERFUL NEMATOCIDE	DUAL BENEFIT: NUTRITION + PROTECTION
✓ Controls nematodes effectively ✓ Suppresses soil-borne pests ✓ Stimulates soil microbes ✓ Improves soil texture and aeration ✓ Enhances root development	✓ Repels nematodes, termites, grubs ✓ Slow-release NPK nutrition ✓ Improves soil organic carbon ✓ Enhances soil fertility naturally ✓ Safe for organic farming
Application Rate: Field crops: 150-200 kg/acre Vegetables: 200-250 kg/acre Orchards: 1-2 kg/tree	Application Rate: Field crops: 100-200 kg/acre Vegetables: 150-250 kg/acre Orchards: 0.5-2 kg/tree Apply 10-15 days before planting

Why Use Oil Cakes?

1. **Slow-release nutrition:** Nutrients become available gradually over 60-90 days
2. **Soil health:** Improve microbial activity and organic carbon
3. **Pest management:** Natural control of soil pests, nematodes, and termites
4. **Cost-effective:** Single input serving multiple purposes

Application Method:

- Incorporate into soil 10-15 days before planting
- Can be mixed with FYM or compost
- Apply in planting pits for fruit crops

Avoid direct contact with tender seedling roots

Part 3: Liquid Bio-Fertilizers - The Growth Enhancers

1. Panchagavya: The Five-Cow Elixir

Traditional Formulation:

- Cow dung: 5 kg
- Cow urine: 4 liters
- Cow milk: 2 liters
- Cow curd: 2 liters
- Cow ghee: 1 liter
- Jaggery: 1 kg

- Ripe banana: 12 fruits
- Tender coconut water: 3 liters

Fermentation: 15-21 days with daily stirring

Application:

Method	Dilution	Frequency	Benefits
Foliar spray	30 ml per liter	Every 10-15 days	Growth promotion
Soil drench	3-5% solution	Every 15 days	Root development
Seed treatment	3% solution	20-30 minutes	Better germination

2. Jeevamrutham: The Microbial Multiplier

Ingredients (for 200 liters):

- Cow dung: 10 kg
- Cow urine: 10 liters
- Jaggery: 1-2 kg
- Pulse flour: 2 kg
- Soil from bund: 1 handful
- Water: 200 liters

Fermentation: 5-7 days in shade with daily stirring

Application Rate: 200 liters per acre, undiluted or diluted 1:10

Why It Works:

- Multiplies beneficial microbes (Azotobacter, PSB, Lactobacillus)
- Fixes atmospheric nitrogen
- Solubilizes phosphorus
- Releases organic acids that unlock soil nutrients

3. Fish Amino Acid: Protein Power

Preparation:

1. Mix fish waste with jaggery (1:1 ratio)
2. Store in airtight container
3. Stir daily for 7-10 days
4. Fermentation complete in 30-45 days

Application:

Method	Dilution	Usage
Foliar spray	1-2 ml per liter	Vegetative stage
Soil drench	5-10 ml per liter	Root zone application
Drip irrigation	1 liter per 200-250 liters	During growth periods

Liquid Bio-Fertilizers

Panchagavya & Jeevamrutham: Nature's Growth Elixirs



Panchagavya

The Five-Cow Elixir

Core Ingredients

Cow dung	5 kg
Cow urine	4 liters
Cow milk	2 liters
Cow curd	2 liters
Cow ghee	1 liter
Jaggery	1 kg
Ripe banana	12 fruits
Tender coconut water	3 liters

Preparation

- Step 1: Mix all cow products
- Step 2: Add jaggery, banana, coconut water
- Step 3: Ferment 15-21 days with daily stirring
- Step 4: Filter before use

Application Methods

Method	Dilution	Frequency
Foliar spray	50 ml/liter	10-15 days
Soil drench	3-5%	15 days
Seed treatment	3%	20-30 min

Why Use Panchagavya

- Complete Growth Regulator**
Contains all essential growth hormones naturally
- Immunity Booster**
Strengthens plant resistance to diseases
- Enhances Quality**
Improves fruit size, taste, aroma, keeping quality
- Microbial Power**
Millions of beneficial microbes per ml



Jeevamrutham

The Microbial Multiplier

Ingredients (200L batch)

Cow dung	10 kg
Cow urine	10 liters
Jaggery	1-2 kg
Pulse flour (besan)	2 kg
Soil from pond	1 handful
Water	200 liters

Preparation

- Step 1: Add cow dung to water, mix well
- Step 2: Add cow urine, jaggery, pulse flour
- Step 3: Add soil (native microbe inoculum)
- Step 4: Ferment 5-7 days in shade, stir daily
- Step 5: Use within 5-7 days for best results

Application Guidelines

Method	Quantity/Acre	Frequency
Soil drench	200 L undiluted	15 days
Diluted	1:10 ratio	15 days
Degraded soil	Weekly	First 2 months

Why Use Jeevamrutham

- Microbial Explosion**
Multiplies beneficial bacteria exponentially
- Nutrient Unlocker**
Fixes N, solubilizes P, releases trapped nutrients
- Root Booster**
Promotes extensive root development
- Low-Cost Solution**
Replaces expensive chemical fertilizers

Part 4: Microbial Bio-Fertilizers

Nitrogen Fixers:

Biofertilizer	Target Crops	N-Fixation Potential	Application Rate
Rhizobium	Pulses, legumes	50-200 kg N/ha	25-30 g/kg seed
Azospirillum	Cereals, millets	10-40 kg N/ha	25-30 g/kg seed
Azotobacter	All crops	10-20 kg N/ha	20-25 g/kg seed

Phosphate Solubilizers:

PSB (*Bacillus megaterium*, *Pseudomonas fluorescens*)

- Converts unavailable P to plant-available form
- Reduces P fertilizer requirement by 20-50%
- Application: 20-25 g/kg seed or 2-4 kg/acre soil application

Biocontrol Agents:

Agent	Target Pests/Diseases	Application
Trichoderma viride	Root rot, wilt, damping-off	4-10 g/kg seed
Pseudomonas fluorescens	Fungal & bacterial diseases	10 g/kg seed
VAM (Mycorrhiza)	Enhanced P uptake	4-5 kg/acre



Nitrogen Fixers - Free Nitrogen from Air



Azospirillum

Converts air nitrogen → Plant food

N-Fixation: 10-40 kg/ha
Application: 25-30 g/kg seed
Fertilizer saving: 25-50%

- ✓ Best for cereals, millets, sugarcane
- ✓ Promotes lateral root growth
- ✓ Produces plant growth hormones
- ✓ Increases yield by 10-25%



Rhizobium

Forms nodules on legume roots

N-Fixation: 50-200 kg/ha
Application: 25-30 g/kg seed
Fertilizer saving: 60-100%

- ✓ Essential for all pulses and legumes
- ✓ Crop-specific strains available
- ✓ Improves protein content in grains
- ✓ Enriches soil for next crop



Azotobacter

Free-living nitrogen fixer

N-Fixation: 10-20 kg/ha
Application: 20-25 g/kg seed
Fertilizer saving: 20-40%

- ✓ Works in all crop types
- ✓ Produces vitamins and amino acids
- ✓ Enhances seed germination
- ✓ Improves stress tolerance

Phosphate Solubilizers - Unlock Hidden P



PSB (Phosphate Solubilizing Bacteria)

Converts unavailable P → Plant-ready P

P availability:	20-200%↑
Application:	20-25 g/kg seed
Fertilizer saving:	20-50%

- ✓ Releases organic acids to dissolve P
- ✓ Works on rock phosphate
- ✓ Enhances root development
- ✓ Improves flowering and fruiting



VAM (Mycorrhiza)

Extends root system 100x

P uptake:	20-200%↑
Application:	4-5 kg/acre
Water use:	30%↓

- ✓ Forms symbiotic relationship with roots
- ✓ Improves drought tolerance
- ✓ Enhances micronutrient uptake
- ✓ Long-term soil benefit

Biocontrol Agents - Natural Protection



Trichoderma viride

Attacks & destroys harmful fungi

Application:	4-10 g/kg seed
Disease control:	60-80%
Fungicide saving:	50-100%

- ✓ Controls root rot, wilt, damping-off
- ✓ Produces antibiotics naturally
- ✓ Promotes root growth
- ✓ Decomposes organic matter



Pseudomonas fluorescens

Multi-action biocontrol warrior

Application:	10 g/kg seed
Disease control:	50-70%
Modes of action:	4+

- ✓ Produces multiple antibiotics
- ✓ Competes with pathogens
- ✓ Induces plant immunity
- ✓ Controls bacterial & fungal diseases

How Bio-Fertilizers Work



Part 5: Organic Pest Management**Botanical Pesticides:****1. Neem Oil (Cold-Pressed)**

- Dosage: 3-5 ml per liter water
- Frequency: Every 7-10 days
- Controls: Aphids, thrips, whiteflies, mites, caterpillars

2. NSKE (Neem Seed Kernel Extract)

- Dosage: 5% solution (50 ml per liter)
- Application: Evening spray for best effect
- Mode of action: Antifeedant and growth disruptor

Farm-Made Preparations: Agni Astra (Strong Botanical Insecticide)**Ingredients:**

- Cow urine: 10 L
- Tobacco leaves: 500 g
- Green chilli: 500 g
- Garlic: 500 g
- Neem leaves: 2 kg
- Water: 10 L

Preparation: Grind, boil 10-20 minutes, cool, ferment 24 hours

Application: Dilute 1:10, spray weekly during pest periods

Biopesticides:

Biopesticide	Target Pests	Dosage	Timing
Beauveria bassiana	Whiteflies, aphids, mealybugs	2-5 ml/liter	Evening application
Metarhizium anisopliae	Termites, grubs, weevils	2-5 ml/liter	High humidity periods
NPV (HB/SL)	Caterpillars (Helicoverpa, Spodoptera)	250-500 LE/acre	Early instar stage
Bt (Bacillus thuringiensis)	All lepidopteran caterpillars	1-2 g/liter	Target small larvae

Physical Traps:

Trap Type	Target Pest	Quantity/Acre	Peak Season in TN
Yellow sticky trap	Whiteflies, aphids, leaf miners	10-15 traps	March-May
Blue sticky trap	Thrips	10-15 traps	Feb-June, Sept-Oct
Pheromone trap	Helicoverpa, Fall armyworm	5-12 traps	Year-round monitoring
Light trap	Nocturnal moths	4-6 traps	June-January (Kharif/Rabi)



Botanical Pesticides

Plant-derived pest controllers

Made from neem, garlic, chilli, tobacco

Key Examples:

Neem Oil: 3-5 ml/liter
Controls: Aphids, whiteflies, mites, caterpillars

NSKE: 5% solution
Anti-feedant + growth disruptor

Agni Astra: Strong botanical mix
Fast-acting pest control

Why Use Botanicals

- ✓ Broad-spectrum pest control
- ✓ No toxic residues on food
- ✓ Biodegrades in 2-7 days
- ✓ Safe for beneficial insects (when used properly)
- ✓ Low-cost, farm-made preparations
- ✓ Multiple modes of action (pests can't resist)

Pest Control
70-85%

Cost/Acre
₹500

Safety
100%



Biopesticides

Living organisms as pest killers

Beneficial microbes that attack pests

Key Examples:

Beauveria bassiana: 2-5 ml/liter
Controls: Whiteflies, aphids, mealybugs

Metarhizium: 2-5 ml/liter
Controls: Termites, grubs, weevils

NPV: 250-500 LE/acre
Controls: Caterpillars (Helicoverpa, Spodoptera)

Bt: 1-2 g/liter
Controls: All caterpillars

Why Use Biopesticides

- ✓ Highly specific (kills only target pests)
- ✓ Zero residue on crops
- ✓ Safe for humans, animals, beneficial insects
- ✓ Pests cannot develop resistance
- ✓ Can be mass-produced
- ✓ Essential for organic certification

Pest Control
80-95%

Cost/Acre
₹1,000

Specificity
100%



Physical Traps

Catch pests before they multiply

Trap adults, prevent egg-laying

Key Trap Types:

Yellow Sticky Trap: 10-15/acre
Controls: Whiteflies, aphids, leaf miners

Blue Sticky Trap: 10-15/acre
Controls: Thrips

Pheromone Trap: 5-12/acre
Monitors & controls: Moths, fruit borers

Light Trap: 4-6/acre
Controls: Nocturnal moths

★ Why Use Traps

- ✓ Early detection of pest outbreaks
- ✓ Mass trapping reduces population
- ✓ Zero chemicals needed
- ✓ Works 24/7 automatically
- ✓ Low cost, long-lasting
- ✓ Essential for IPM programs

Prevention:
60-80%

Cost/Acre
₹1,500

Duration
Season



Farm-Made Solutions

Traditional wisdom meets science

Low-cost, effective, on-farm preparations

Popular Preparations:

Neemastra: Cow urine + neem
Repels sucking pests

Brahmastra: Strong botanical mix
Controls major pests

Arappu Whey: Natural soap solution
Cleans leaves, repels pests

Chilli-Garlic Extract: Spicy deterrent
Stops feeding immediately

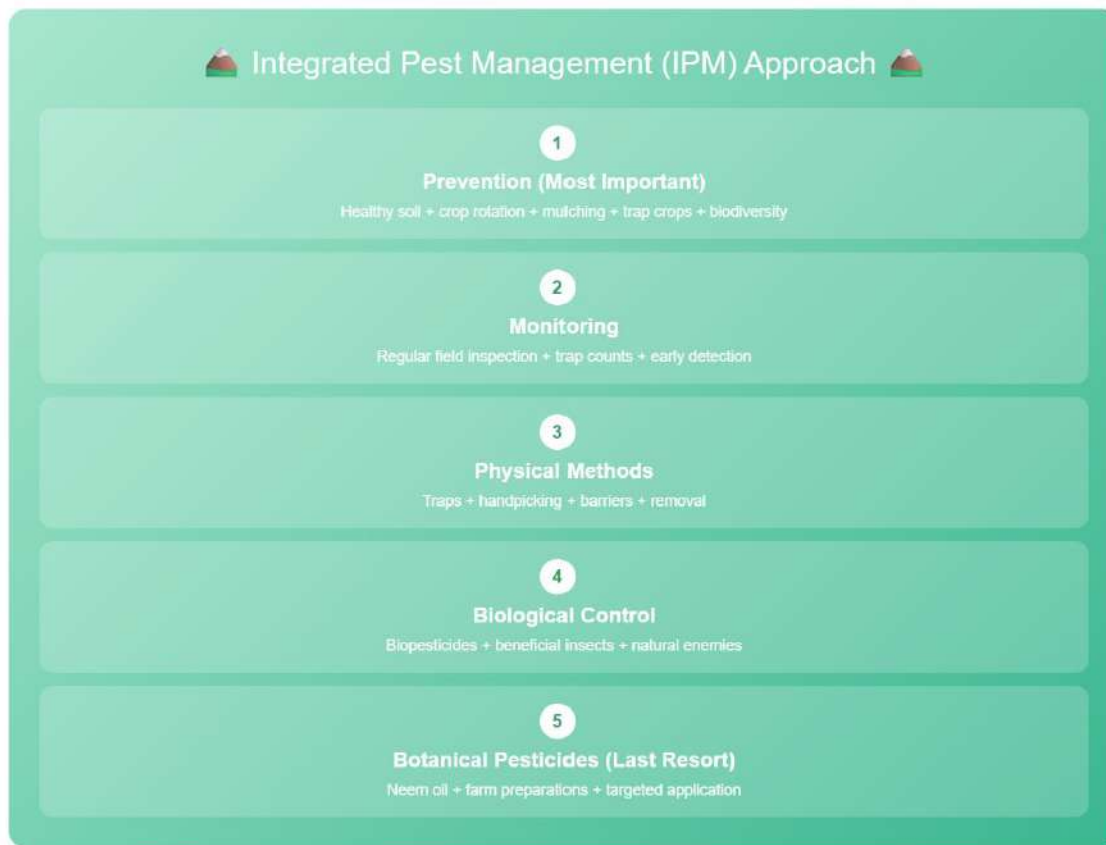
★ Why Make Your Own

- ✓ Extremely low cost (₹100-300/acre)
- ✓ Uses farm resources
- ✓ No dependence on market
- ✓ Fresh preparations work best
- ✓ Easy to make with simple tools
- ✓ Empowers farmers

Pest Control
60-75%

Cost/Acre
₹200

Freshness
Best



Part 6: Soil Conditioners and Amendments

Natural Amendments:

Amendment	Key Nutrients	pH Effect	Application Rate	Best For
Rock phosphate	P: 28-32%, Ca: 30-35%	Neutral	100-150 kg/acre	Acidic soils
Bone meal	P: 12-15%, Ca: 22-28%	Neutral	100-150 kg/acre	All crops
Wood ash	K: 5-7%	Alkaline	50-80 kg/acre	Acidic soils
Gypsum	Ca: 32-34%, S: 17-18%	Neutral	1-2 tons/acre	Sodic/clay soils
Agricultural lime	Ca: 35-40%	Alkaline	1-2 tons/acre	Acidic soils (pH <5.5)

Modern Organic Conditioners:

1. Biochar

- Carbon content: 50-80%

- Application: 2-5 tons/acre
- Benefits: Water retention, nutrient holding, carbon sequestration
- Best for: Sandy soils, dry zones of Tamil Nadu

2. Coconut Coir Pith Compost

- Organic carbon: 25-35%
- Application: 2-5 tons/acre
- Benefits: Improves water holding, soil structure, microbial activity
- Ideal for: Red soils, laterite soils

3. Zeolite

- CEC: 80-120 meq/100g
- Application: 500-1000 kg/acre
- Benefits: Nutrient retention, slow-release carrier, reduces leaching
- Best for: Sandy soils, fertigation systems

Part 7: Plant Growth Promoters

Natural Growth Stimulants:

Promoter	Key Components	Application	Benefits
Seaweed extract	Auxins, cytokinins, betaines	2-3 L/acre foliar	Stress tolerance, flowering
Humic acid	50-60% humic substances	1-2 L/acre foliar	Nutrient uptake, root growth
Banana extract	High K, cytokinins	1:10 dilution	Flowering, fruiting
Aloe vera extract	Polysaccharides, amino acids	1:10-1:20 dilution	Stress tolerance

Implementation Guide for Tamil Nadu Farmers

Season-wise Application Schedule:

Pre-Monsoon (April-May):

1. Soil testing and pH correction (lime/gypsum if needed)
2. FYM/compost incorporation (10-15 tons/acre)
3. Green manure crop sowing (if applicable)
4. Biochar/coir pith compost application

Monsoon/Kharif (June-October):

1. Seed treatment with biofertilizers
2. Jeevamrutham application every 15 days

3. Panchagavya foliar spray every 10-15 days
4. Pest monitoring with traps
5. Need-based botanical pesticide application

Post-Monsoon/Rabi (November-January):

1. Vermicompost application (1-2 tons/acre)
2. Oil cake incorporation
3. Continue liquid biofertilizers
4. Seaweed/humic acid for growth boost

Summer (February-April):

1. Mulching with organic matter
2. Stress-relief sprays (seaweed, aloe vera)
3. Intensive trap monitoring
4. Compost heap preparation for next season

Cost-Benefit Analysis:
Investment for 1 Acre Organic Vegetable Farm:

Input	Quantity	Cost (₹)
FYM/Compost	10 tons	8,000
Vermicompost	2 tons	6,000
Oil cakes	200 kg	4,000
Biofertilizers (complete set)	As required	2,000
Panchagavya ingredients	4 batches	1,500
Jeevamrutham ingredients	8 batches	2,000
Botanical pesticides	Season	3,000
Biopesticides	Season	4,000
Traps	25 units	1,500
Total		₹32,000

Returns:

- Premium price for organic produce: 30-50% higher
- Reduced input costs in subsequent years

- Improved soil health and water retention
- Long-term sustainability

Success Stories from Tamil Nadu

Case Study 1: Organic Vegetable Farmer, Ooty

Transition from chemical to organic in 3 years

Background: 2-acre vegetable farm, heavy chemical use causing soil degradation

Intervention:

- Year 1: 50% organic inputs + soil testing
- Year 2: 75% organic + complete FYM incorporation
- Year 3: 100% organic with full biological pest control

Results:

- 40% reduction in input costs
- 35% premium on organic certified produce
- Soil organic carbon increased from 0.8% to 1.8%
- Complete elimination of chemical pesticides

Case Study 2: Cardamom Estate, Nilgiris

Integrated organic management in plantation crop

Approach:

- FYM: 25 kg per plant annually
- Vermicompost: 5 kg per plant biannually
- Panchagavya spray monthly
- Trichoderma for rhizome rot control
- Mulching with green leaves

Outcomes:

- Disease incidence reduced by 60%
- Yield increased by 25%
- Organic certification achieved
- Market linkage with premium buyers

Common Challenges and Solutions

Challenge 1: "Organic inputs give lower yields initially"

Solution:

- Transition gradually (3-5 years for full conversion)
- Build soil organic matter systematically
- Use concentrated inputs (oil cakes, vermicompost) strategically
- Supplement with liquid biofertilizers during critical stages

Challenge 2: "Labor-intensive preparation of inputs"**Solution:**

- Form farmer groups for bulk preparation
- Use simple mechanization (drum mixers, grinders)
- Purchase ready-made certified organic inputs
- Train family members in preparation techniques

Challenge 3: "Pest control is difficult without chemicals"**Solution:**

- Implement preventive measures (trap crops, mulching)
- Use multiple control methods (IPM approach)
- Monitor regularly with traps for early detection
- Accept tolerable pest levels (organic farming allows 5-10% damage)

Challenge 4: "Market linkage for organic produce"**Solution:**

- Obtain organic certification (NPOP/PGS-India)
- Join farmer producer organizations (FPOs)
- Direct marketing through farmers markets
- Contract farming with organic brands

Quality Standards and Certification**NPOP (National Programme for Organic Production) Standards:**

Allowed Inputs: ✓ All inputs mentioned in this guide ✓ Farm-made preparations ✓ Naturally occurring minerals ✓ Biological control agents

Prohibited: ✗ Synthetic fertilizers ✗ Chemical pesticides ✗ Genetically modified organisms
✗ Sewage sludge

PGS-India (Participatory Guarantee System):

- Group-based certification
- Lower cost than third-party certification
- Suitable for small and marginal farmers
- Peer review and local verification

Future Trends in Organic Inputs

1. Customized Microbial Consortia

- a. Development of location-specific beneficial microbe combinations

2. Nano-formulations

- a. Improved delivery systems for botanical pesticides and nutrients

3. Waste-to-Resource Technologies

- a. Converting agricultural waste into high-value organic inputs

4. Digital Tools

- a. Mobile apps for organic input preparation and application scheduling

5. Climate-Resilient Inputs

- a) Organic solutions specifically for drought, flood, and heat stress

Conclusion

The transition to organic farming is not merely a shift in inputs—it's a complete paradigm change in how we view agriculture. As this comprehensive guide demonstrates, nature provides us with all the tools needed for productive, sustainable farming. From the wisdom of Panchagavya to the precision of biopesticides, from the foundation of FYM to the innovation of biochar, organic inputs offer a complete solution for soil health, plant nutrition, and pest management.

For Tamil Nadu's farmers, particularly those in ecologically sensitive zones like the Nilgiris, adopting organic inputs isn't just about certification or premium prices—it's about preserving our soils for future generations, protecting our water sources, and maintaining the biodiversity that makes our agriculture resilient.

The journey requires patience, learning, and commitment, but the rewards—healthy soils, safe food, sustainable livelihoods, and environmental protection—make it worthwhile. Start small, learn continuously, and grow organically. Your soil will thank you, your crops will show it, and your farm will thrive for generations to come.

Resources and Support

Government Schemes:

- Paramparagat Krishi Vikas Yojana (PKVY)
<https://www.myscheme.gov.in/schemes/pkvy>
- Mission Organic Value Chain Development for North East Region (MOVCD-NER)
<https://movcd.dac.gov.in/home>
- National Mission on Sustainable Agriculture (NMSA) <https://nmsa.dac.gov.in/>

Training Centres in Tamil Nadu:

- ICAR – Krishi Vigyan Kendras (Tamil Nadu) <https://agritech.tnau.ac.in/kvk/kvk.html>
- Tamil Nadu Agricultural University (Nammazhvar Organic Farming Research Centre)
<https://tnau.ac.in/site/directorate-cm/nammazhvar-organic-farming-research-centre/>
- State Department of Agriculture (Organic Farming Cell)
<https://spc.tn.gov.in/policy/organic-farming-policy/>



Volume: 05 Issue No: 12

LONG MELON- AN UNDERUTILIZED SALAD VEGETABLE CROP

Article ID: AG-VO5-I12-21

¹*V. Krishnan, ¹V. Kanthaswamy, ¹M. S. Marichamy, ²N. Bavya and ³B. Bavithra,

¹Faculty, ²PG Scholar & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and
Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Long melon, botanically called *Cucumis melo* var. *utilissimus* ($2n = 14$), belonging to family Cucurbitaceae, is also called as Kakri, Snake melon, Serpent cucumber, Snake cucumber, Serpent melon, Armenian cucumber and Rental cucumber. Long melon is a cucurbitaceous crop used as salad or even some times cooked as vegetables. It is mainly warm season crop grown in tropical and sub-tropical climate. Young and tender fruits are harvested for salad. They are climbing types and low growing or ground types all require similar husbandry. The ground types tend to be the larger fruits. The climbing varieties need strong trellises for support and the fruit requires netting *i.e.* fruit hung in net bags tied to the trellis for support of their considerable weight.

ORIGIN AND DISTRIBUTION

Long melon has its origin Middle East, Asia and northern Africa, which is the primary centre of origin and India is the secondary centre of origin. It is cultivated in India and Pakistan. In India it is cultivated in Rajasthan, Punjab and Uttar Pradesh.

BOTANICAL DESCRIPTION

Annual climber that grows up to 75-90 cm long. Flowers are yellow in colour. Plant are monoecious in nature Corolla is slowly, yellow in colour. Petals are 5 in numbers; united stamens are attached to calyx tubes. Ovary is inferior. The period of bud development stage is completed within 12-15 days in male and 11-13 days in female flower. The fruits are slender, elongated and are curved and often irregularly curled. Its skin is thin, light to dark green in

colour, smooth or present with longitudinal furrows and green stripes. The tender fruits are on an average 20-85cm long, 2.5-2.9 cm girth, cylindrical and 330-360 g fruit weight. The fruit is crisp, succulent and sweet.



RELATED SPECIES OF LONG MELON

1. ***Cucumis anguria* (West Indian Gherkin or Burr Gherkin):** Fruit are small, elongated, and has a bumpy texture. It is commonly used for pickling.
2. ***Cucumis metuliferus* (Kiwano or Horned Melon):** Fruit are spiky orange skin and green, jelly-like flesh. It is elongated and has a unique, mildly sweet flavour.
3. ***Cucumis myriocarpus* (African Horned Melon):** Similar to the kiwano, it has a spiky orange exterior and green, gelatinous interior. It is elongated and often used in African cuisine.
4. ***Cucumis sativus* (Cucumber):** Long cucumber varieties, such as the English cucumber, are elongated and can be similar in shape to long melons.

USES OF LONG MELON

1. Long melon is used in the form of salad, cooked as vegetables, and preserved in the form of sweets.
2. Long melon popularly known as Kakri is valued for tender fruits which are eaten raw along with salt and pepper.

3. Due to its cooling effect this is very popular during summer months in most part of the country.

CLIMATE AND SOIL

Long melon is adapted to tropical and sub-tropical climates. It is sensitive to frost. Hot and dry weather favours vegetative growth and fruit development. It prefers well-drained sandy loam or loamy sand soils with pH in the range of 6.0-7.0. The light soils are desirable for early maturity. It cannot grow under shade.

COMMERCIAL VARIETIES

1. Punjab Long Melon-1: Released by PAU, Ludhiana. It is an early maturing selection from local material collected from Hoshiarpur, Punjab. The fruits are long, thin and light green. Average yield is 215 quintals per hectare.

2. Karnal Selection: A prolific bearer. Fruit tender, light green, long thin, flesh crisp with good flavour.

3. Arka Sheetal: It is developed by selection from the local material collected from Lucknow, Uttar Pradesh. The fruits are light green covered with soft hair and medium long (22 cm long and 7.8 cm girth) with shallow furrows. Average fruit weight is 100g and yield is 350 quintals per hectare.

4. Pusa Utkarsh: First early maturing variety of long melon for spring summer season cultivation under North Indian plains. Fruits sets ready for first harvest in 45-50 days after sowing in spring summer season. Fruits are slightly curved, medium long (length 52 cm), thin (diameter 2.4 cm), light green, smooth non-prominent ridges, shiny with tender skin and crispy flesh. Each fruit weighs 130-145 g at marketable stage. Average fruit yield is 29.2 t/ha during spring summer season.

SOWING AND NURSERY MANAGEMENT

Long melon seeds are sown at a rate of 2-2.5 kg/ha. The seeds should be pretreated with Captan or Thiram at a rate of 2 g/kg of seed before planting. To start the germination process, seeds should be soaked in water overnight and stored in moist gunny bags for a couple of days in a warm environment.

The appeal of this crop lies in its reduced seed prices, which are 80–90% lower than those of greenhouse cucumber (Parthenocarpic variety), and the fact that growers may cultivate disease-free seed together with fruit production. As a result of temperature fluctuations, the long-

melon seeds, which have a fragile seed coat, have poor germination in normal conditions. Therefore, for healthy root growth and establishment, seedlings should be cultivated under polyhouse or poly-tunnel structures with the aid of plastic pro-trays with cells that are 1.1/2" in size and filled with soilless medium like coco peat, vermiculite, and perlite in a 3:1:1 ratio. Each cell contains one seed. Growers can nurture seedlings in tiny nursery poly-bags with the aid of vermicompost, sand, and soil in the mixed ratio of 2:1:1 if pro-trays are not available. Within 22 to 25 days after seeding, the seedlings are prepared for transplantation into IP-net houses and polyhouses for July and August.

TRANSPLANTING

Long melon is produced on the north Indian plains as a summer and rainy season crop. Summer crops are planted from late February to March, while rainy season crops are planted from June to July. Sowing in riverbeds takes place from November to December. Sowing is done at a depth of 1 cm. Planting takes place in raised beds 1.80-2.40 m wide, with 60-90 cm spacing between plants, depending on the variety and other circumstances. By using the double row approach and maintaining a plant-to-plant spacing of 30 x 30 cm and a row-to-row spacing of 50 x 50 cm, seedlings are transplanted. Although the winter crop should be transplanted between October and November under the NV polyhouse construction, the transplanting and sowing may have begun under the IP-net house during the final first week of August

INTERCULTURAL OPERATION

MANURES AND FERTILIZER

It required 15-20 tonnes of FYM applied at the time of field preparation, 100kg nitrogen, 75kg phosphorus and 50kg potash per hectare are applied. Whole of phosphorus and potash and half of nitrogen is applied at the time of bed preparation. The remaining nitrogen is applied in two split doses, the first 20 days after sowing and the second twenty days thereafter

IRRIGATION AND WEEDING

Long melon requires maintenance of adequate moisture in the soil for vegetation growth and fruit development. The first irrigation is given immediately after sowing facilitate proper seed germination. Subsequent irrigations in summer months are given at 3-4 day intervals. In rainy season, irrigation is given only if there is a prolonged dry spell. Two shallow hoeing should be done before spreading of vines to control weeds. Apply fluchloralin or trifluralin (0.75-1.5 kg/ha) as pre plant soil incorporation at two weeks before sowing.

SPECIAL PRACTICES

Trellis or Bowe use a sturdy trellis, bower or vertical support structure. A strong lattice or A-frame can work well. Ensure it is tall and robust enough to support the weight of the growing melons. Netting is added support, you can use netting or mesh to help hold the fruit in place and prevent it from sagging. Plant melons at least 2-3 feet apart to allow room for growth and easy access.

PEST OF LONG MELON

1. Aphid and Thrips: They damage the plant by sucking the leaf sap. In young stage, cotyledonary leaves crinkle and in severe cases the plants wither. In grown up vines, the affected leaves turn yellow and plant loses its vigour and yield. To control spray the crop with Thiamethoxam @ 5 g/15 l of water.

2. Fruit fly (*Bactrocera cucurbitae*): The damage is caused by the maggots of the fly. Generally, fruits are attacked in the early immature soft stage, and they do not develop properly. They may rot and drop down prematurely if the infestation is severe. Those fruits which do not drop and are picked, and are unfit for consumption, as they have a number of abominable maggots in the pulp. Due to attack of this pest, the fruits may also be deformed. The humid hot weather is most suitable for its attack and generally 50 -60% loss is caused to the vegetable crop. Foliar application of Neem oil @ 3.0% is given to cure the crop from fruit fly pest.

3. Red pumpkin beetle (*Aulacophora foveicollis*): The damage continues to be caused even in the later stages of the crop, but it is not so much serious as in the case of seedlings. The larval stage of the pest also does considerable damage as it bores into the roots, stems and even the fruits on which the attack starts from the portion resting on the ground. The attacked plants wither and die and the affected fruits become unmarketable spraying of Malathion @ 2 ml/l of water Carbaryl @2 gm/l will help to get rid of beetles.

DISEASES OF LONG MELON

1. Powdery mildew (*Erysiphe cichoracearum*): The foliage and green stems is characterized by the appearance of tiny, white to dirty grey spots (sometimes with a reddish-brown tinge). They become powdery as they enlarge. The effect of severe infestation may be premature death of the vines. Fruits also get covered with the white powdery mass but this is not common. The fruits remain undersized and sometimes are deformed To control this disease, spray of water soluble Sulphur @ 20 gm/10 Ltr of water 2-3times with interval of 10 days.

2. Downy mildew (*Pseudoperonospora cubensis*): The leaves resemble those of mosaic mottling. The pale green areas are separated by islands of darker green. Soon the spots become well-defined. They are angular, yellow coloured and often restricted by the veins on the upper To control this disease, spray the crop with Dithane M-45 or Dithane Z-78.

3. Cucurbit phyllody: Application of Furadan @ 5 kg/acre at the time of sowing will helps to prevent from this disease. If infestation is observed, then spraying of Dimecron @ 0.05% at the interval of 10 days is done.

PHYSIOLOGICAL DISORDER AND CONTROL MEASURES

1. Sand Blasting: High winds usually result in stem injury and withering of transplants, especially in the section of the stem that is exposed to the wind direction. Overwhelming winds will dehydrate leaves, causing them to wilt from the edges inward. Significant losses might result from the disruption of whole fields. This is managed by avoiding transplantation in strong winds and also by creating windbreaks throughout fields.

2. Drought Stress: Cucurbits are highly drought-sensitive. Fruits, which normally contain 85–90% water, might suffer during a drought. Long melon can transpire a lot of water on hot summer days and frequently generates a lot of large-sized leaves. Fruit growth is impacted by severe drought stress, which leads to difficult to sell fruit. The fruits lose their proper size and become limp and wrinkled. Fruit that has been exposed to the sun due to drought will similarly become Sunburned. To manage, avoid moisture stress during the formation of the vine, the pre-flowering period, the blooming stage, and the fruit stage of the crop. During the summer, protect the crop from the sun's rays.

3. Poor Pollination: Long melon is a cross-pollinated crop; hence pollination is necessary to yield fruit. To ensure proper fruit development, pollinators frequently need to visit a flower many times on the day it opens. When pollination is insufficient, many fruits will seem misshaped and tiny. Low pollination rates can also be caused by extremely hot and low temperatures that impair pollen viability. Bees may have trouble finding the blooms if too much nitrogen is utilised (leading in excessive vegetative growth) if plants were not spaced appropriately. To manage provide pollinators to have a comprehensive set fruit set and high yields. When 5–10% of the plants have open blooms in the field under typical circumstances, place one or two beehives per hectare. Clusters of beekeeping should be arranged along the edge of the field, with more hives

being positioned inside the bigger fields. Spraying pesticides early in the day, when flowers are open and insects are busily pollinating plants, is not advised

HARVESTING

The maturity symptoms indicating the requirement of harvest are the skin of the melon should be firm and not overly shiny or glossy. The flesh should be firm but not too hard. It should give slightly when pressed, indicating that the melon is ripe but not overripe.

The fruits are harvested when they have attained good size (20-30cm long) but are still tender and succulent with hairy growth. Fruits of long melon attain marketable maturity in one week after fruit setting. Depending upon variety, season and location long melon takes 70-90 days from sowing to reach harvestable maturity. Harvesting is done at 2-3 days intervals. Over-mature fruits become tough, pale yellow and dull and show separation of carpel when cut transversely. The yield of long melon is about 350-400q.ha⁻¹

POST HARVEST MANAGEMENT PRACTICES

Post-harvest management is crucial to maintaining the quality and extending the shelf life of long melon.

- 1. Cleaning and Washing:** After harvesting, the fruits should be washed with clean water to remove dirt, debris, and any pesticide residues. This step is important for maintaining hygiene and reducing the risk of contamination.
- 2. Drying:** The washed fruits should be air-dried in a shaded, well-ventilated area. Excess moisture on the surface of the fruits can lead to fungal growth, so it is important to ensure they are properly dried before storage.
- 3. Grading and Sorting:** Sort and grade the long melons based on size, shape, and quality. Uniformity in size and appearance is important for market preferences. Remove any fruits with signs of defects, such as cracks, blemishes or disease. This helps in ensuring that only high-quality produce reaches the market.
- 4. Packaging:** Use breathable packaging materials such as perforated plastic bags, wooden crates, or cardboard boxes. Proper packaging helps in maintaining the freshness of the fruits by allowing adequate ventilation. Ensure that the fruits are protected from direct sunlight and physical damage during packaging. Soft cushioning materials can be used to prevent bruising during transportation.

5. Storage: Long melon should be stored at a temperature of 10-15°C (50-59°F) with a relative humidity of 85-90%. These conditions help in maintaining the freshness and extending the shelf life of the fruits. For short-term storage, keep the fruits in a cool, dry place away from direct sunlight. Proper ventilation in the storage area is essential to prevent the buildup of ethylene gas, which can cause premature ripening.

6. Transportation: Long melons are to be transported over long distances, maintaining a cool chain is important to preserve their quality. Refrigerated vehicles can help in keeping the fruits at the desired temperature during transit. Ensure that the fruits are protected from direct sunlight during transportation to prevent heat damage and dehydration.

7. Marketing: The long melons reach the market, the fresher they will be delay in marketing can lead to a reduction in quality and shelf life. Present the fruits attractively by displaying them in a clean and organized manner. Proper labelling and packaging also help in attracting customers.

POST-HARVEST TREATMENTS

1. Fungicidal Treatment: Post-harvest treatment with fungicides can help in reducing the risk of fungal infections, especially in fruits that are to be stored for extended periods. However, it is important to follow recommended guidelines to ensure food safety.

2. Waxing: Applying a thin layer of edible wax can help in reducing moisture loss and improving the appearance of the fruits. Waxing also helps in extending the shelf life of long melon

Volume: 05 Issue No: 12

META ANALYSIS OF YIELD IN INTEGRATED NUTRIENT MANAGEMENT ON GROUNDNUT CULTIVATION

Article ID: AG-VO5-I12-22

K.Maruthupandi ¹, K.Ramachandran ², R.Balamurugan ³, B.Devaraju ⁴**R.Kamaleshwaran ⁵, M.Prabu ⁶ and M.Selvaraj ⁷**^{1,2,3,4}Department of Agronomy, ⁵Department of Soil Science and Agricultural Chemistry,⁶Department of Horticulture, ⁷Department of Agricultural Engineering, , Gandhigram Rural Institute-Deemed to be University,Chinalapattil, TamilNadu, India-624302.

*Corresponding Author Email ID: kmpaki@gmail.com

Abstract

The yield Meta analysis was conducted to study the effect of integrated nutrient management on groundnut, The treatment consisted of ten different integrated nutrient management treatments practices. The integration of inorganic fertilizers along with seed inoculation of biofertilizers viz., *Rhizobium* and phosphates solubilising bacteria (PSB) recorded significantly higher pod and haulm yield of summer groundnut as compared to rest of the treatments. Combined application of 75 % recommended dose of nitrogen (RDN) and 25 % RDN through vermicompost or farm yard manure (FYM) along with seed inoculation of *Rhizobium* and phosphates solubilising bacteria (PSB) recorded higher pod and haulm yield on groundnut (Jesal Joshi and A. G. Patel 2021). The experiment 10 treatments,viz. T₀, control, T₁, 10 t FYM/ha; T₂, 50 kg P₂O₅/ha; T₃, 50 kg P₂O₅ + 10 t FYM/ha; T₄, 50 kg P₂O₅ + 50 kg K₂O/ha; T₅, Rhizobium; T₆, 10 t FYM/ha + Rhizobium; T₇, 50 kg P₂O₅/ha + Rhizobium; T₈, 50 kg K₂O + 10 t FYM/ha and T₉, 50 kg P₂O₅ + 50 kg K₂O/ha + Rhizobium. Application of Rhizobium culture in combination with 50 kg P₂O₅ + 50 kg K₂O/ ha resulted in the highest pod and seed weight/plant. The inoculation of Rhizobium culture along with 50 kg P₂O₅ +50 kg K₂O/ha showed 45% increment in pod yield (from 1.37 to 1.95 t/ha) over the control. The highest haulm yield (3.57 t/ha) was obtained with FYM 10 t/ha,(Data *et al.*, 2014). The experiment pooled results indicated that application of 75% RDF + Vermicompost 2 t ha⁻¹ to groundnut crop recorded significantly higher yield attributes and yield

viz., number of pods per plant (18.15), pod weight per plant (13.53), pod (2343 kg ha⁻¹) and haulm (3802 kg ha⁻¹) yield of groundnut (Patel *et al.*, 2024).

Key words: Groundnut; INM; Bio-fertilizer; yield, Vermicompost; FYM.

Introduction

India is the second largest producer of groundnut in the world which produces around 10.30 million tones of groundnut from 4.96 million hectares of land and 2075 kg ha⁻¹ productivity under irrigation (Anonymous, 2023). Groundnut is unique and important legume cum oilseed crop in India. It is largely grown in Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra (Jesal Joshi and A. G. Patel 2021). Groundnut (*Arachis hypogaea* L.) commonly referred to as the "POOR MAN'S ALMOND," is an annual herbaceous legume that is autotetraploid and self-pollinating. Such a plant exists, and every component of it boosts the farmer's income. Ranking 13th among food crops and 4th in importance among oilseed crops worldwide, it is the world's greatest source of edible oil (Ramanathan, 2001). The kernel also contain carbohydrates (6.0 to 24.9%), minerals and vitamins (Das, 1997). Groundnut area, production and productivity of Gujarat were 1.76 million hectares, 4.53 million tonnes and 2570 kg ha⁻¹, respectively (Anonymous, 2023). Groundnut is an important annual legume in the world, mainly grown for oilseed, food and animal feed (Pande *et al.*, 2003). It is a safe, cheap and renewable N source for crops, which are capable of fixing N₂ and therefore profitable for agriculture and eco-friendly for environment (Vance, 2001).

The crop also has potential to increase soil fertility, check soil erosion along with meeting the requirement of vegetable oil and protein. Groundnut is an exhaustive crop, hence integrated use of nutrients from chemical, organic and biofertilizers is the most efficient way to supply plant nutrients for sustained crop productivity and improved soil fertility (Singh *et al.*, 2002). The continuous use of high levels of chemical fertilizers is adversely affecting the sustainability of agricultural production and causing environmental pollution. In coming decades a major issue in designing sustainable agricultural system will be the management of soil organic matter and the rational use of organic inputs such as animal manures, crop residues, green manures, sewage, sludge and food industry waste. However, since organic manures cannot meet the total nutrients need of modern agriculture, integrated use of nutrients from fertilizers and organic sources seems to be a need of the time. The basic concept underlying the integrated nutrient management system (INMS), nevertheless, is the maintenance and possible improvement of soil fertility for

sustained crop productivity on long term basis and also to reduce fertilizer input cost (Patel *et al.*, 2024).

Discussion

Significantly higher number of pods per plant and dry weight of pods per plant were recorded by the application of RDF + *Rhizobium* + PSB. It was followed by 75% RDN + 25% N through vermicompost + *Rhizobium* + PSB and 75% RDN + 25% N through FYM + *Rhizobium* + PSB. The plants were healthy with the application of combination FYM, vermicompost and biofertilizers and it was reflected in their yield attributes viz. number of pods and dry weight of pods per plant. The lower number of pods per plant and dry weight of pod per plant were recorded by 50% RDN + 50% N through FYM. Application of fertilizer along FYM and vermicompost increased the number of pods and dry weight of pods per plant significantly and further increased the pod and haulm yield of summer groundnut. Mohapatra and Dixit (2010) also reported that pod and haulm yield were significantly higher with the application of FYM, vermicompost and biofertilizers.

Application of recommended dose of nutrients through different sources (viz. chemical fertilizers, FYM, vermicompost etc.,) along with biofertilizers (viz., *Rhizobium* and PSB) significantly increased the pod and haulm yield of summer groundnut. Application of RDF along with biofertilizers (*Rhizobium* + PSB) resulted in significantly higher pod and haulm yield and it was closely followed by 75% RDN + 25% N through vermicompost + *Rhizobium* + PSB and 75% RDN + 25% N through FYM + *Rhizobium* + PSB. In case of pod and haulm yield, the latter two treatments in combination with FYM and vermicompost were found statistically at par. The increase in pod yield was 22.8, 22.0 and 20.9 per cent than that of 50% RDN + 50% N through FYM. This might be attributed to rapid mineralization of chemical nitrogen and slow supply of nitrogen from FYM and vermicompost along with biofertilizers which might have met the nitrogen requirement of crop at critical stages of growth. Further, FYM and vermicompost act as nutrient reservoirs and upon decomposition produce organic acids, thereby absorbed ions are released slowly during entire growth period leading to improvement in crop yield attributes and ultimately pod and haulm yield of groundnut. The percent increase in pod yield by fertilizing the crop with 100% RDF + *Rhizobium* + PSB (T₁₀), 75% RDN + 25% N through vermicompost + *Rhizobium* + PSB (T₉) and 75% RDN + 25% N through FYM + *Rhizobium* + PSB (T₇) was tune to the tune of 22.8, 22.0 and 20.9 per cent, respectively over 50% RDN + 50% N through FYM.

Similar trend was observed by (Abraham and Thenua ,2010). Dhadge and Satpute (2014) also reported significantly higher the pod and haulm yield due to integration of inorganic and organic sources of nutrients.

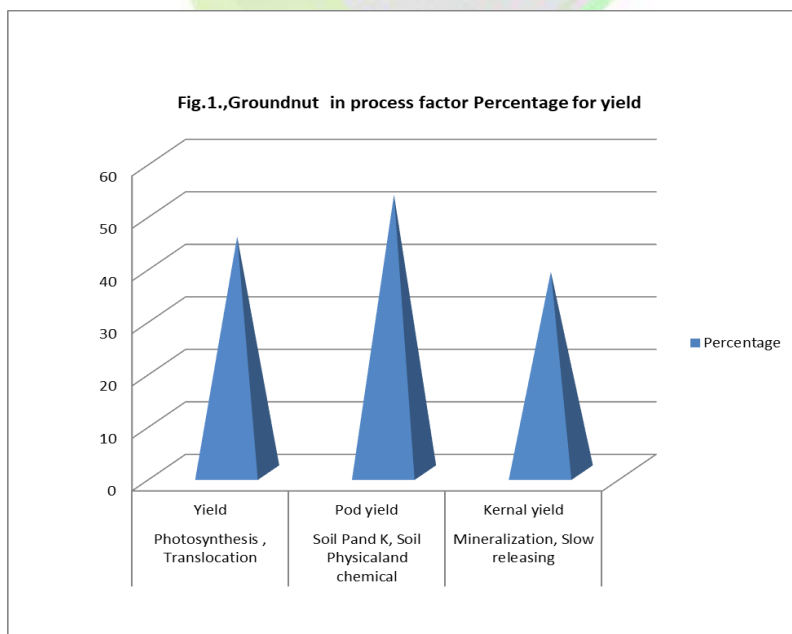
Data on a higher number of pods per plant (18.55, 17.75, and 18.15 in 2022, 2023 and pooled, respectively) were observed when 75% RDF + Vermicompost 2 t ha⁻¹ (T₃) was applied in both the year of experiment and the pooled study. This was statistically comparable to the application of 75% RDF + FYM 5 t ha⁻¹ (T₂) and 100% RDF (T₁) in both the year of experiment and the pooled study. The percent increase in number of pods per plant at harvest was to the tune of 7.56, 3.42, 38.81 and 23.26 over treatment T₁, T₂, T₄ and T₅, respectively. The higher number of pods per plant could be because of the combined effect of vermicompost and inorganic fertilizers that provided balanced nutrition throughout growth period resulted in favourable effect on pod formation.

These results are in agreement with the findings of Konthoujam *et al.* (2013) in soybean, Jesal and Patel (2021) in groundnut and Pandey *et al.* (2022) in soybean. Application of 75% RDF + Vermicompost 2 t ha⁻¹ (T₃) gave significantly higher pod weight per plant (13.70, 13.37 and 13.53 g in 2022, 2023 and pooled study, respectively) which was statically at par with 75% RDF + FYM 5 t ha⁻¹ (T₂) and 100% RDF (T₁) in both the year of experiment as well as in pooled study. Application of fertilizer along vermicompost and FYM increased the pods weight per plant significantly and further increased the pod and haulm yield of *kharif* groundnut. The increase in the pod weight could be due to continuous supply of (Fig.1.,) macro and micro nutrient to the crop which help in photosynthesis, assimilation and translocation of photosynthate from source to sink. Jesal and Patel (2021) and Vala *et al.*(2017) also reported higher pod weight with the application of vermicompost and FYM.

Among different treatment, application of 75% RDF + Vermicompost 2 t ha⁻¹ (T₃) gave significantly highest pod (2371, 2315 and 2343 kg ha⁻¹) and haulm yield (3840, 3765 and 3802 kg ha⁻¹) in 2022, 2023 and pooled, respectively in both year and pooled study, which was remained statistically at par with 75% RDF + FYM 5 t ha⁻¹ (T₂) and 100% RDF (T₁) in both year of experiment as well as pooled study . Higher pod yield could be attributed to favourable changes in physical and chemical characteristics of the soils which might have enabled better pod formation. Moreover, the positive influence of these treatments through immediate supply of

nutrients from inorganic sources especially at the early stage of the crop and slow and steady supply of nutrients from vermicompost and FYM throughout the crop growth period improved adequate biomass production and improvement in yield parameters resulting in higher pod and haulm yield. Similar findings are reported by Ola *et al.* (2013) , Bhosale and Pisal (2017) , Kumar *et al.* (2019), Jesal and Patel (2021) and Arsalan *et al.* (2024) . Groundnut yield components were significantly influenced by different nutrient management. Significantly highest pod weight/plant and kernel weight/plant were recorded under treatment, where seeds were inoculated with *Rhizobium* culture and crop received 50 kg P_2O_5 and 50 kg K_2O /ha. The results confirm the findings of Zalate *et al.* (2009). The lowest pod and seed weight/plant were observed under the control plot.

Pod and haulm yields were significantly influenced by different nutrient management. *Rhizobium* inoculation of groundnut seed along with soil application of 50 kg P_2O_5 /ha and 50 kg K_2O /ha recorded significantly maximum pod yield (1.96 t/ha). This may be owing to the fact that seed inoculation with biofertilizer and soil phosphorus and potassium significantly increased the yield components and yield of groundnut. Zalate *et al.* (2009) also reported similar result. Minimum pod yield was recorded in the control plot. Highest Stover yield was obtained with application of 10 t FYM/ha. The FYM not only supplied macro and micro nutrients, viz. N, P, K, and S but also improved soil physical condition and availability of nutrients thereby increased yield of crops. Similar result was reported by Mohapatra *et al.* (2010).



Conclusion

It was concluded that to get maximum productivity, profitability and energy-use efficiency from groundnut in acidic soils of Tripura, the crop should be managed with *Rhizobium* inoculation along with application 50 kg P_2O_5 + 50 kg K_2O /ha. Based on the two-year experimental findings, it is concluded that the combined application of organic manures and fertilizers had significant and positive effect on growth, yield and quality of groundnut crop. The application of 75% RDF (9.38: 18.75: 00: 18.75 kg N: P_2O_5 : K_2O : S ha^{-1}) along with 2 t ha^{-1} of vermicompost recorded higher number of pod, pod weight, pod yield and haulm yield of groundnut. This nutrient management practice is effective in improving the protein content in kernel of groundnut. It may be concluded that application of 100% RDF + *Rhizobium* + PSB resulted in significantly higher pod and haulm yield, protein content, oil yield and also higher net realization and B: C ratio of summer groundnut.

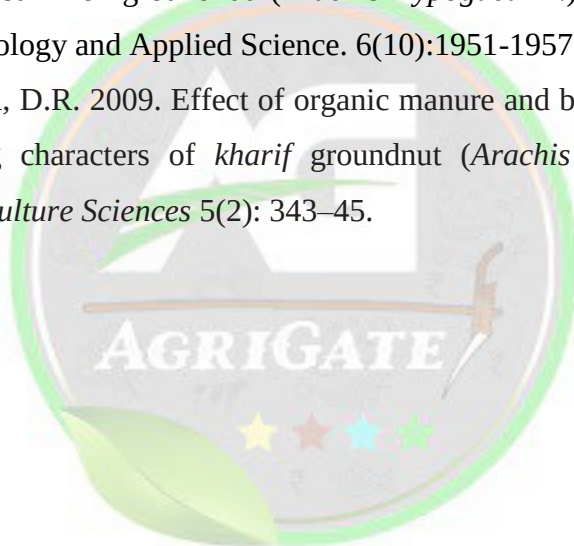
From the Meta analysis yield is influenced by Integrated nutrient methods and quantity, manures, enriched manures and recommended dose of fertilizers. Here 45% of yield increase through photosynthesis and translocation process with in INM. Fertilizers with INM involved the Pod yield 53% increased by availability of soil Phosphorus and potash and Soil physical and chemical process influenced with in INM and compared to these two with INM of Agronomic practices increased kernel yield 38.3% increased by Mineralization and slow releasing nutrient process.

Reference

- Jesal Joshi and A. G. Patel. 2021. Effect on Integrated Nutrient Management on Productivity, Quality and Nutrient Uptake on Summer Groundnut (*Arachis hypogaea* L.). *International Journal of Plant & Soil Science* 33(23): 316-322.
- Datta, M., G.S. Yadav and Sandip Chakraborty 2014. Integrated nutrient management in groundnut (*Arachis hypogaea*) in subtropical humid climate of north-east India. *Indian Journal of Agronomy* 59 (2): 322–326.
- Patel, KK., JM Patel, PP Chaudhari, KJ Chauhan, RM Patel and DM Patel 2024. Effect of integrated nutrient management on growth, yield and quality of groundnut (*Arachis hypogaea* L.) under north Gujarat condition. *International Journal of Research in Agronomy*, SP-7(10): 706-709.

- Anonymous 2023. Data retrieved from <https://commodities.cmie.com>. Accessed on 19th April,2024.
- Ramanathan T 2001. Genetic improvement of groundnut. Associated Publishing Company, New Delhi: 2001;9.
- Das, PC. 1997. Oilseeds Crops of India. Kalyani Publishers, Ludhiana India. 1997; 80-83.
- Pande, S., Bandyopadhyay, R., Blummel, M., Rao, J., Thom, D. and Navi, S.S. 2003. Disease management factors influencing yield and quality of sorghum and groundnut crop residue. *Field Crop Research*. 84(1-2): 89–103.
- Vance, C.P. 2001. Symbiotic nitrogen fixation and phosphorus acquisition, plant nutrition in a world of declining renewable resources. *Plant Physiology* 127: 390–97.
- Singh, H., Mishra, D. and Nahar, N.M. 2002. Energy use pattern in production agriculture of a typical village in Arid Zone India (Part I). *Energy Conversion and Management* 43: 2,275–86.
- Mohapatra AKB, Dixit L 2010. Integrated nutrient management in rainy season groundnut. *Indian Journal of Agronomy*. 55(2):123-127.
- Abraham T, Thenua OVS 2010. Influence of organic and inorganic sources of nutrients and their methods of application on growth and yield attributes of groundnut. *Indian Journal of Agricultural Research*. 44 (3):216-220.
- Dhadge SM, Satpute NR 2014. Effect of integrated nutrient management on growth, yield and quality of summer groundnut. *International Journal of Agricultural Science*. 10:314 - 316.
- Arsalan M, Latif A, Khan M, Syed S, Ullah R, Ahamd I 2024. Integrated effect of organic amendments and chemical fertilizers on yield of groundnut and soil health under rainfed condition. *Journal of Applied Research in Plant Sciences*. 5(1):99-104.
- Bhosale NA and Pisal AA 2017. Effect of nutrient management on productivity of summer groundnut (*Arachis hypogaea* L.). *Advanced Agricultural Research and Technology Journal*. 1(1):88-91.
- Konthoujam ND, Tensubam BS, Athokpam HS, Naorem BS, Shampurailatpam D 2013. Influence of inorganic, biological and organic manures on nodulation and yield of soybean [*Glycine max* (L.) Merrill] and soil properties. *Australian Journal of Crop Science*. 7(9):1407-1415.

- Kumar CR, Ganapathy M, Ganesamoorthy D, Karthikeyan A, Saravanaperumal M, Murugan G 2019. Effect of INM on growth, yield and quality parameters of irrigated groundnut (*Arachis hypogaea* L.) var.VRI-2 for sandy loam soils.Plant Archives. 19(2):745-749.
- Ola BL, Pareek BL, Yadav RS, Shivran AC, Sharma OP 2013.Influence of integrated nutrient management on productivity and quality of groundnut in Western Rajasthan. Annals of Agricultural Research. 34(2):156-159.
- Pandey DD, Tiwari RB, Keshry PK 2022. Effect of integrated nutrient management on growth and yield of soybean (*Glycine max* L.). The Pharma Innovation Journal. 11(6):2228-2230.
- Vala FG, Vaghasia PM, Zala KP, Buha DB 2017. Effect of integrated nutrient management on productivity of summer groundnut (*Arachis hypogaea* L.). International Journal of Current Microbiology and Applied Science. 6(10):1951-1957.
- Zalate, P.Y. and Padmani, D.R. 2009. Effect of organic manure and biofertilizers on growth and yield attributing characters of *kharif* groundnut (*Arachis hypogaea*). *International Journal of Agriculture Sciences* 5(2): 343–45.



PROTECTING OUR OCEANS: ADDRESSING THE THREAT OF IUU FISHING

Article ID: AG-VO5-I12-23

***Akash Arul. A¹ and F. Rose Ruby²**

UG Students, College of Fisheries Science, St. Devasahayam Institute of Fisheries Science & Technology, Amanattantheri, Kanniyakumari, Tamil Nadu - 629 193.

*Corresponding Author Email ID: aakashdifst@gmail.com

Abstract

Illegal, unreported, and unregulated (IUU) fishing refers to activities by vessels operating without state authorization or in violation of laws. Unreported fishing includes catches not disclosed to relevant authorities, while unregulated fishing occurs in regions lacking oversight. IUU fishing severely impacts food security, especially in developing nations, with actual catches often exceeding reported figures by significant margins. This phenomenon endangers local economies reliant on fisheries, highlights the need for effective management by regional fisheries management organizations (RFMOs), and has led to international initiatives aimed at combating these practices, such as the FAO's International Plan of Action initiated in 2001. Key species affected include tuna, sharks, and various shellfish.

Keywords: food security, IUU, Regional fisheries management organizations, unregulated, unreported.

Introduction

IUU fishing, meaning “Illegal, Unreported and Unregulated” is a phrase used for over fifteen years, by international bodies, national governments, media, Non-Governmental Organizations, etc. The word "officialization" was first used in 1997 during the 16th meeting of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), a commission established under the Convention enacted for the management of fisheries resources in Antarctica.

Illegal, unreported and unregulated (IUU) fishing is a complicated regulatory issue that happens in every ocean basin (Sumaila et al., 2006). It is a broad phrase that encompasses a vast

variety of fishing activity. Both in the high seas and in regions under national authority, IUU fishing is present in all kinds and dimensions of fisheries. It may occasionally be connected to organized crime and encompasses all facets and phases of fish collection and use.

According to Agnew et al. (2008), "IUU fishing" refers to all unlawful and often unreported operations on the high seas that fall within the purview of regional fisheries management organizations (RFMOs) as well as any illegal and unreported activities within Exclusive Economic Zones (EEZs).

The FAO states that IUU fishing "remains a major global threat to the long-term sustainable management of fisheries and the maintenance of productive and healthy ecosystems as well as to the stable socio-economic condition of many of the world's small-scale and artisanal fishing communities" (FAO 2014). The environmental implications of IUU fishing are comparable to overfishing, involving the depletion of target populations (Pomeroy et al., 2007), changes in trophic dynamics following unsustainable harvest (Field et al., 2009), and habitat destruction induced by destructive fishing practices (McManus, 1997).

Definitions

Illegal fishing

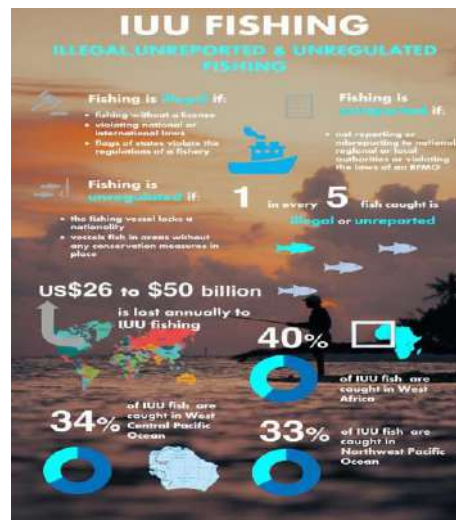
Fishing performed by national or foreign vessels in seas within the authority of a State, without the authorization of that State, or in breach of its laws and regulations. In contravention of national laws or international responsibilities, especially those pledged by collaborating States to a relevant regional fisheries management body.

Unreported fishing

Which are carried out within the jurisdiction of a relevant regional fisheries management organization and have not been reported or have been misreported, in violation of that organization's reporting procedures; or which have not been reported or have been misreported to the appropriate national authority, in violation of national laws and regulations.

Unregulated fishing

In the area of application of a relevant regional fisheries management organization that are undertaken by boats without nationality, or by those flying the flag of a State not party to that organization.



Examples of IUU fishing:

- Fishing without a license or quota for certain species.
- Failing to report catches or making false reports.
- Keeping undersized fish or fish that are otherwise protected by regulations.
- Fishing in closed areas or during closed seasons, and using prohibited fishing gear.
- Conducting unauthorized transshipments (e.g., transfers of fish) to cargo vessels.
- The environmental implications of IUU fishing are comparable to overfishing, involving the depletion of target populations (Pomeroy et al., 2007), changes in trophic dynamics following unsustainable harvest (Field et al., 2009), and habitat destruction induced by destructive fishing practices (McManus, 1997).

What are RFMO's?

Organizations for regional fisheries management. Area of usually stocks emphasis on high oceans, but may include EEZ waterways of riparian nations under area of competence. Contracting parties join RFMO. Geographical and species coverage expanding.

Establish management and conservation measures;

- Catch certification, trade documentation
- Flag State responsibility
- Vessel registration,
- licensing, Monitoring trans-shipment
- Boarding and Inspection
- Vessel Lists (IUU, Authorized Vessels)

IUU Fishing in Historical Perspective

- The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) first used the term "illegal, unreported, and unregulated fishing" in a 1997 study that detailed illegal fishing occurring in the Southern Ocean's Exclusive Economic Zones (EEZs). As demand built for a comprehensive response to illicit fishing, the FAO committed to the development of a worldwide plan, the International Plan of Action to Prevent, Deter and Eliminate illicit, Unreported and Unregulated Fishing (FAO 2001).
- The Marine Stewardship Council (MSC), which was established in 1997 to help customers buy seafood from sustainably managed fisheries, was one of the several non-governmental groups to address the issue (Roberts, 2012).
- A joint statement by European Union and United States of America describes the phenomenon in similar terms stating that 'IUU fishing is a global phenomenon with devastating environmental and socio-economic consequences, particularly for coastal communities in developing countries who rely on fisheries for their livelihoods or for protein' (Damanaki and Lubchenco, 2011)

Effects of IUU fishing

- IUU fishing poses a direct danger to food security and socioeconomic stability in many regions of the world.
- The nations most at danger from IUU fishing are developing nations that rely on fisheries for both food security and export revenue.
- For example, overall captures in West Africa are believed to be 40 percent greater than reported catches.
- Many crew members on IUU fishing vessels are from impoverished and underdeveloped regions of the world, and they typically work in risky conditions.

SI No.	Main IUU Species
1)	Abalone
2)	Tunas
3)	Alaska pollock
4)	Reef fish

5)	Billfish
6)	Crabs
7)	Shark
8)	Turtles
9)	Squid
10)	Salmon
11)	Sharks
12)	Sea urchins
13)	Seas cucumber

Effects of IUU fishing on seafood industry

- In addition to avoiding the operating expenses of sustainable fishing methods, fishermen and businesses that participate in IUU fishing may profit financially by exceeding harvesting restrictions. Because of this, the seafood industry and law-abiding fishermen may face unfair competition from their illegally captured goods. Additionally, because the United States imports most of its seafood, IUU fishing produces an imbalance of poorer quality items in the seafood market while concurrently hurting the sustainability of global marine resources.

Economic losses caused by IUU fishing

The UN Food and Agriculture Organization (FAO) estimates that unauthorized, unreported, and unregulated fishing operations cause the annual loss of 11–26 million tons of fish, with an estimated economic worth of US\$10–23 billion. Target 4 of Goal 14 of the Sustainable Development Agenda, which was adopted by the UN General Assembly in 2015, specifically calls on the international community to "effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices" by 2020 in order to lessen this impact. To encourage long-term conservation and sustainable use of fisheries resources the FAO Conference established the FAO Code of Conduct for Responsible Fisheries.

Conclusion

Illegal, unreported, and unregulated (IUU) fishing encompasses several illegal practices: fishing without appropriate permissions, failing to report or misreporting catches, and

operating without nationality in areas overseen by regional fisheries management organizations (RFMOs). This issue threatens food security and economic stability, particularly in developing nations dependent on fisheries. IUU fishing results in significant financial losses, estimated between \$10-23 billion annually due to the unauthorized capture of 11-26 million tons of fish. The United Nations calls for effective regulation to combat this issue, highlighting the need for sustainable practices in fisheries management. Significant species affected include various fish, crabs, and sea turtles. IUU fishing undermines lawful fishers by creating unfair competition and contributes to ecological degradation, impacting marine biodiversity.

Reference

- Leonardo, A., & Deeb, N. (2022). *Illegal, unreported and unregulated (IUU) fishing in Indonesia: Problems and solutions*. IOP Conference Series: Earth and Environmental Science, 1081, 012013. <https://doi.org/10.1088/1755-1315/1081/1/012013>
- Igbani, F., Ezon-Ebi, E., & Terenyu, J. (2025). *Effects of IUU and other illegal fishing activities on aquatic biodiversity: A review*.
- Le Gallic, B., & Cox, A. (2006). An economic analysis of illegal, unreported and unregulated (IUU) fishing: Key drivers and possible solutions. *Marine Policy*, 30(6), 689–695.
- Ma, X. (2020). An economic and legal analysis of trade measures against illegal, unreported and unregulated fishing. *Marine Policy*, 117, 103980.
- Muir, M. (2010). Illegal, unreported and unregulated fishing in the Circumpolar Arctic. *Arctic*, 63, 373–378. <https://doi.org/10.14430/arctic1509>
- Currey, R., Eisert, R., & Sharp, B. (2015). *Detecting and managing potential ecosystem effects of fishing on marine mammals in the Ross Sea: Research, monitoring and proposed MPA designation under CCAMLR*.

Volume: 05 Issue No: 12

SNAP MELON- A GUT COOLING UNDERUTILIZED VEGETABLE CROP

Article ID: AG-VO5-I12-24

¹Kanthaswamy, V., ^{1*}V. Krishnan, ¹M. S. Marichamy, ²N. Bavya and ³B. Bavithra,

¹Faculty, ²PG Scholar & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Snap melon, botanically called *Cucumis melo* subsp. *agrestis* var. *momordica*; ($2n=2x=24$), belonging to family Cucurbitaceae is native to India, where it is widely cultivated and is commonly called split melon, Phut, Phoot Kakadi, Phootikai, Pottu vellari. It is generally known as 'phut,' which meaning 'to divide'. Fruit cracking can occur longitudinally or randomly, with skin peeling occurring in some cases. Immature fruits are cooked or eaten raw. Snap melon is a source of high fruit acidity, a trait that has been utilized to breed uniquely flavoured melon cultivars.

ORIGIN AND DISTRIBUTION

Snap melon is probably originated in the tropical regions of Africa and Asia. It is a very popular vegetable of arid region. It is commonly grown as a rain fed crop in Rajasthan and Gujarat. Snap melon belongs to the genus *Cucumis* and species *melo* and has been placed under the botanical variety *momordica*. It is widely cultivated in many Indian states, including Rajasthan, Gujarat, Punjab, Haryana, Uttar Pradesh, West Bengal, and some other northeastern states. It is also cultivated in other countries of Southeast Asia, for instance Myanmar and Vietnam.

BOTANICAL DESCRIPTION

It is an annual, vine 5- 6 m long, leaf petiolate 3-4 lobed, surface rough. It is monoecious, which means that individual plants produce both male and female flowers on the same plant. Staminate flowers appear first, latter on pistillate flowers. Flowers yellow in colour. Snap melon

fruits can be round, acorn, oblate, ovate, elongated, elliptical, or pyriform. Fruit flesh colours range from cream, yellow, to orange. Generally, they range from 5-7 inches in diameter.



RELATED SPECIES

1. ***Cucumis melo* var. *reticulatus* (Cantaloupe):** This is the well-known cantaloupe or muskmelon, characterized by its netted rind and sweet, orange flesh. It is closely related to snap melon but is cultivated primarily for its sweet flavour. Uses for widely consumed as a fresh fruit, cantaloupe is also used in desserts, salads, and beverages.
2. ***Cucumis melo* var. *inodorus* (Honeydew Melon):** Honeydew melon is another close relative of snap melon, known for its smooth, waxy rind and sweet, green flesh. Unlike snap melon, honeydew is non-aromatic, hence the name inodorus. used for Honeydew is popular in fruit salads, smoothies, and as a standalone snack.
3. ***Cucumis melo* var. *conomon* (Pickling Melon):** This variety, known as the pickling melon, is primarily used in East Asia. The fruits are small, with a smooth rind and firm flesh, making them

ideal for pickling. It is widely used in East Asian cuisine for pickling; this variety is less commonly consumed fresh.

4. *Cucumis melo* var. *tibish* (Sudanese Melon): This is a lesser-known variety cultivated in Sudan and surrounding regions. It has a smooth rind and a mildly sweet to neutral flavour, similar to other non-aromatic melons. Used in salads, as a fresh fruit, or in traditional Sudanese dishes.

NUTRITIVE VALUE (ON FRESH WEIGHT g /100 g)

Constituents	Quantity
Moisture	95.70 g
Carbohydrate	3.00 g
Protein	0.30 g
Fat	0.10 g
Vitamin A (IU)	265.0 IU
Minerals	0.40 g

MEDICINAL USES

Cooling and intense cleanser, act as a moisturizer and used in the treatment of burns and abrasions Improve appetite and relieve stomach pain. Help to relieve constipation and vomiting. The seeds are antitussive, digestive, febrifuge, and vermifuge; the roots are diuretic and emetic.

FLORAL BIOLOGY

Anthesis occurs early in the morning. Male and female flowers typically open at dawn, between 5:00 and 7:00 A.M, depending on ambient factors such as temperature and lighting. The flowers bloom for a few hours, usually until late morning or early afternoon (between 11:00 AM and 1:00 PM). Following this stage, the flowers begin to close.

CLIMATE AND SOIL

Snap melon prefers warm and humid climate. For the germination of seed temperature between 30-35°C is required whereas temperature range of 32-37°C proves conducive for fruit growth and development. It is mainly grown as an intercrop in maize and cotton where plants get enough humidity for growth. Snap melon can be grown in different types of soils, however, humus rich with ample provision of drainage is considered ideal. The optimum pH of soil is 7 for its cultivation

CULTIVATED VARIETIES

I. Local cultivars

1. Grism Bahar: It is mainly suitable for summer season. Fruits are 30-40 cm long with proper thickness. Single vine bears 4-5 fruits. Immature fruits have green colour whereas ripe fruits develop yellow colour.

2. Kwari Bahar: It is suitable for kharif season. Fruits 25-35 cm long with green stripes. Flesh colour light pink and 4-5 fruits are harvested from a plant.

II. Released varieties

1. AHS 10: It is an early, high yielding selection from the local land races released by Central Institute for Arid Horticulture, Bikaner. The fruits are oblong and medium in size, 850-950 g in weight, 17-20 cm in length and 9.7- 10.5 cm in diameter. Edible flesh thickness is 2.1-2.6 cm, the fruit cavity 5.5-6.1 cm wide. Its average yield is 225-230 q/ha.

2. AHS 82: A selection from the local genetic materials collected in the arid regions and released by Central Institute for Arid Horticulture, Bikaner. It yields an uniform, medium sized and long fruits. Plants are vigorous with average vine lengths of 2.25 m. Each vine bears 4.5-5.0 fruits, per plant gives yield of 245-250 q/ha. The flesh has 4.3-4.9% TSS and it is tasty and light pink in colour

SOWING AND PLANTING

Seed rate per hectare sowing is 4-5 kg are required. Two crops are taken in Rajasthan by sowing in kharif as well as in summer season. In the hilly regions, sowing starts from 15th March and continues up to 15th May. In rainy season, seeds are spaced at 3 x 2 m and in summer season the spacing can be closer due to comparatively less vigorous growth of vine. When snap melon is grown as intercrop in maize and cotton, seeds are sown after every 4-5 rows of main crops. Seeds germinate within 4-6 days of sowing.

INTERCULTURAL OPERATION

MANURES AND FERTILIZER

Snap melon crop grown as a mixed or inter crop does not require any additional manure or fertilizer application. In general, FYM @ 15-20t.ha⁻¹ are mixed at the time of field. In addition to this, 30kg N, 50 kg P and 50kg ha⁻¹.

IRRIGATION AND WEEDING

Irrigation is not required in rainy season crop. However, frequent watering at the interval of 5-6 days. Adequate drainage in rainy season is must because vine is very much sensitive to water logged condition. During early stage of plant growth, weeds are removed to avoid crop weed competition.

SPECIAL PRACTICES

Giving support to the vine by erecting bower, it promoting growth and facilitates harvesting of the fruit. Plant ties or clips to attach the vines to the structure. Avoid tying too tightly to prevent damage to the plant.

PHYSIOLOGICAL DISORDER AND CONTROL MEASURES

1. Blossom End Rot: Sunken, dark, and water-soaked lesions at the blossom end of the fruit. Caused due to calcium deficiency, inconsistent watering or poor calcium uptake. Remedial measure is to maintain consistent moisture ensure even soil moisture by watering regularly and avoiding drought or water logging. Use calcium supplements or calcium-rich fertilizers if soil tests indicate a deficiency. Maintain soil pH between 6.0 and 6.8 for optimal nutrient uptake.

2. Fruit Cracking: Cracks or splits on the surface of the fruit, often due to rapid changes in moisture levels. Control by maintain consistent soil moisture and avoid sudden changes. Apply fertilizers according to soil tests to avoid over-fertilization.

3. Sunburn: Sunken, discoloured areas on the fruit due to excessive sun exposure, caused due to high temperatures and direct sunlight on the fruit. Remedial measure is to use shade cloth or provide natural shading with plants to protect fruit from intense sunlight. Train vines and prune leaves to reduce sun exposure to the fruit.

PEST OF SNAP MELON

1. Leaf Miner (*Liriomyza spp.*): Larvae create serpentine or blotchy mines within the leaf tissue. These mines start as narrow, winding tunnels and can expand, causing the leaf to turn brown and dry out. Extensive mining can reduce the leaf's ability to photosynthesize, impacting plant growth and yield. Damaged leaves may become more susceptible to fungal infections and other pests. Control measure is to use insecticides specifically targeted at leaf miners. Products containing spinosad or neem oil can be effective. Always follow label instructions to avoid harming beneficial insects

2. Red Pumpkin Beetle (*Aulacophora foveicollis*): Adults and larvae eat on Kachri leaves, stems, and flowers, causing defoliation and stunted growth. They burrow into the fruits, causing direct damage and rendering them unmarketable. Control measures include handpicking beetles and larvae to minimize their population. Infestations can be controlled by applying carbaryl or malathion at the proper levels.

DISEASES OF SNAP MELON

1. Powdery Mildew (*Erysiphe cichoracearum*): White, powdery spots on the upper surfaces of leaves, stems, and fruit. Spots may enlarge and coalesce, causing leaf distortion and premature leaf drop. In severe cases, the fungus can cover the entire plant, impacting photosynthesis and fruit quality. Control measure is to apply fungicides as a preventive measure or at the first sign of infection. Products containing sulphur, potassium bicarbonate, or specific fungicides like triflumizole or myclobutanil can be effective.

2. Angular Leaf Spot (*Pseudomonas lachrymans*): Small, water-soaked lesions that become angular due to the leaf veins. The spots often have a yellow halo. Severe infections can cause premature leaf drop, impacting plant health and fruit development. In severe cases, the bacterium can move through the plant, causing systemic symptoms. Control measure is to use bactericides containing copper-based products, such as copper hydroxide or copper sulfate. These can help reduce bacterial populations and manage disease.

HARVEST

Fruit maturity or harvest readiness is indicated by incipient rind splitting or abscission. Immature fruits are harvested for salad. Full ripe fruits are harvested for dessert purpose. While harvesting the fruits, care should be taken to harvest the fully ripe fruits before they split.

POST HARVEST MANAGEMENT PRACTICES

Snap melon fruits are perishable and can be stored for 2-4 days at room temperature in cold store at 2-4°C and 85-90% RH. However, the fruits can be stored for 2-3 weeks. It is traditionally utilised for making 'rasayna'. Ripe fruits are utilised for making squash, syrup, ice-creams and candies. Approximately 250-300 quintal yield is realized in kharif season whereas summer crop yields 200-250 q/ha.

UNDERSTANDING THE MIGRATORY ENDOPARASITIC NEMATODES IN BANANAS

Article ID: AG-VO5-I12-25

Berliner, J.^{*1}, Giribabu, P.¹, Manimaran, B.² and Sellaperumal, C.²

^{*1}ICAR-National Research Centre for Banana, Tiruchirappalli, Tamil Nadu

²ICAR-Indian Institute of Spice Research, Calicut, Kerala, India

*Corresponding Author Email ID: berliner.j@gmail.com

Introduction

Banana plants are affected by several nematode pests, including lesion nematodes (*Pratylenchus* spp.), the burrowing nematode (*Radopholus similis*), root-knot nematodes (*Meloidogyne* spp.), spiral nematodes (*Hoplolaimus* spp.), and the reniform nematode (*Rotylenchulus reniformis*). Among these, two important microscopic worms, lesion nematodes (*Pratylenchus* spp.) and the burrowing nematode (*R. similis*) cause major root damage in many banana-growing regions..



Figure 1. Damage caused by lesion nematodes (*Pratylenchus* spp.) in banana: (A) toppling of plants; (B) blackened roots with nematode-infested lesions; (C) pared corm showing nematode-induced lesions.

Both nematodes are migratory endoparasites, meaning they enter the plant roots and move from place to place within the root tissues while feeding. Their feeding and migration create dark lesions inside the roots and reduce the plant's ability to absorb water and nutrients. As a result, banana plants grow slowly, become weak, and produce fewer bunches (Gowen, 1995). Understanding their damage-causing ability, life cycle, reproduction, and distribution in soil is important for farmers, students, and anyone working with banana crops to develop proper management strategies

Lifecycle:

The life cycle of both lesion nematodes (*Pratylenchus* spp.) and the burrowing nematode (*R. similis*) in banana follows a similar pattern. Eggs are laid inside or near the root tissues. After hatching, the second-stage juveniles begin searching for a host root and enter it by puncturing the surface with their stylets. Once inside, they start feeding and migrating through the cortex. The juveniles then undergo three additional moults before reaching the adult stage. Reproduction is usually sexual (amphimictic), involving both males and females; however, parthenogenesis can also occur, especially when males are few or absent. A single female of either species can lay around 50–100 eggs in her lifetime, although the exact number varies with environmental conditions. Under favourable temperature and moisture, these nematodes complete their life cycle within 3–6 weeks, enabling rapid population buildup in banana fields with continuous host availability.

Symptomatology:

Lesion nematodes (*Pratylenchus* spp.) and the burrowing nematode (*R. similis*) secrete digestive enzymes from their oesophageal glands, mainly cellulases, pectinases, hemicellulases, and other cell-wall-degrading enzymes. These enzymes are injected through the stylet into cortical cells, where they begin dissolving cellulose, pectin, and the middle lamella. As the cell walls weaken, the nematodes feed on the partially digested cell contents and migrate both intercellularly (between cells) and intracellularly (through living cells), rupturing tissues and destroying cell contents. The combined effect of cell-wall breakdown, leakage of cellular contents, and oxidation of phenolic compounds leads to characteristic lesions: small purplish-black spots in *Pratylenchus* infections and larger reddish-brown tunnels in *R. similis*. This enzymatic degradation, along with dual-pathway migration, causes progressive necrosis and browning of banana roots and corms. However, because these symptoms can resemble those

caused by other biotic or abiotic factors, identifying the exact nematode based on symptoms alone is difficult. Therefore, proper diagnosis by a trained nematologist is essential to confirm that the symptoms observed in banana plants are specifically due to nematode infection.

How they look under a microscope:

Humans cannot see nematodes with the naked eye because of their very small size, transparent bodies, and hidden habitat within roots and soil. Therefore, experts identify them by extracting them from roots or soil and examining them under a microscope. Identification usually begins with observing the general body shape. Lesion nematodes (*Pratylenchus* spp.) have females with a simple, straight body, a low and flat head, and a rounded or blunt tail. In some species, males may be absent or occur only in small numbers. The burrowing nematode (*R. similis*) is slightly larger, and the males show a clear head dimorphism with a raised lip region. They also possess a well-developed bursa—a flap-like extension at the tail—used to hold females during mating. These distinct morphological features help scientists confirm the species during laboratory diagnosis (Orton Williams & Siddiqi, 1973).

Despite their minuscule size, nematodes can multiply rapidly when continuous susceptible hosts are available, leading to several easily visible symptoms in banana plants. These symptoms appear both below the ground in the roots and above the ground in the aerial parts, as summarized below.

Below-Ground Symptoms:

Root damage becomes evident through the appearance of characteristic lesions. When infested roots are cut longitudinally, small purplish-black lesions that remain localized are typically seen in *Pratylenchus* spp. infections. In contrast, *R. similis* produces larger and deeper reddish-brown lesions. Heavy infestation of *R. similis* in the corm can lead to the formation of dark, sunken areas known as Blackhead disease (Sarah et al., 1996). These internal symptoms are often the most reliable indicators for field diagnosis; however, confirmation by a nematologist is essential to verify the presence of nematodes.

Above-Ground Symptoms:

Damage to the root system disturbs the movement of water and nutrients within the plant, making the banana plant weak. Prolonged impairment of nutrient uptake reduces plant vigour, resulting in gradual yellowing, stunting, and slow growth, often giving the plant a nutrient-deficient appearance. Severe nematode infestation can also weaken anchorage, causing plants—

especially those bearing bunches—to topple suddenly. This is well documented in cases of *R. similis* and is known as Toppling disease (Gowen & Quénéhervé, 1990). However, toppling or easy falling of banana plants during strong winds has also been observed in fields heavily infested with *Pratylenchus* spp.

Management of Migratory Endoparasitic Nematodes:

Though we are centering on the migratory endoparasitic nematode, the management is non-specific and common for majority of the nematodes.

Sanitation of Planting Material:

The main focus in the management strategy is to prevent the nematode entry, using clean planting material, using non-nematode infested soil and maintaining soil health. The nematodes spreads mainly through infected suckers and corms, so a zero-tolerance approach is required. The most effective methods include: Hot water treatment (52–55°C for 15–20 minutes) Tissue-culture plantlets that are guaranteed nematode-free (Stover & Simmonds, 1987). However, the banana farmers in India rarely uses this hot water treatment as it requires maintaining the treating water at 52-55oC and a slight variation in temperature may affect the normal growth of the suckers. Hence, the farmers generally prefer to follow simple paring and sun-drying. Moreover, the farmers started preferring tissue culture grown banana plants to avoid this treatment difficulty. .

Crop Rotation and Soil Management:

Monocropping of banana is commonly practiced in most banana-growing regions, including Tamil Nadu. In some wetland areas, banana is rotated with rice, while in garden land conditions it is often rotated with cotton, groundnut, sorghum, onion, and other crops. In certain regions, banana is intercropped with onion, coriander, or vegetables; and in parts of North India, it is also intercropped with mustard, cabbage, cauliflower, chilli, or tomato. Among these systems, continuous monocropping is not advisable, as it encourages the buildup of migratory endoparasitic nematodes in the soil, eventually leading to severe yield losses. Crop rotation with wetland rice helps reduce nematode populations, whereas crops such as groundnut, sorghum, and solanaceous vegetables are highly susceptible and may worsen the problem. Mustard acts as an antagonistic crop, while cabbage and cauliflower can reduce nematode numbers to some extent. Non-host crops such as marigold (*Tagetes* sp) are also effective in lowering nematode populations. Therefore, farmers' awareness of the susceptibility or resistance of different crops is

essential, and adopting a logical crop rotation system is crucial for long-term management of plant-parasitic nematodes and keeping their population below the economic threshold level.

Improving Soil Health:

Many nematodes in the soil are not harmful to banana plants. Free-living nematodes—such as bacterial feeders, fungal feeders, omnivores, and predators—coexist with plant-parasitic nematodes and contribute significantly to soil health by aiding processes like nutrient mineralization. Maintaining healthy soil through proper agronomic practices is therefore more effective than relying solely on pesticides for keeping plant-parasitic nematode populations below the economic threshold level. This can be achieved by applying sufficient organic amendments, using compost, keeping fields weed-free, practicing propping, and ensuring good drainage, all of which strengthen the root system and enhance the plant's tolerance to nematode damage. Application of nematicides should be reserved only as a last resort and used as a curative measure in severe infestations.

Conclusion

Migratory endoparasitic nematodes, such as lesion nematodes (*Pratylenchus* spp.) and the burrowing nematode (*R. similis*), are hidden pests that weaken banana roots, reduce water and nutrient uptake, and cause symptoms like dark lesions, Blackhead disease, and Toppling disease. Effective management requires understanding their life cycle, morphology, and symptoms, along with proper diagnosis. Preventive strategies—including clean planting material, tissue-culture plantlets, crop rotation with non-host or antagonistic crops, and maintaining healthy soil through organic amendments and good drainage—are key to keeping populations below economic thresholds. Nematicides should be used only as a last resort. Integrated practices focusing on sanitation, soil health, and crop rotation provide the most sustainable protection for banana plantations.

References

- Orton Williams, K.J. & Siddiqi, M.R. 1973. *Radopholus similis*. CIH Descriptions of Plant-Parasitic Nematodes, Set 2, No. 27.
- Gowen, S. 1995. Banana Nematodes and Their Control. CAB International.
- Gowen, S. & Quénéhervé, P. 1990. Nematode parasites of bananas, plantains and abaca. In Plant Parasitic Nematodes in Subtropical and Tropical Agriculture.
- Sarah, J.L., Pinochet, J., & Stanton, J. 1996. Nematode parasites of bananas and plantains.

Volume: 05 Issue No: 12

WILD MUSK MELON- A MEDICINALLY VALUED UNDERUTILIZED VEGETABLE CROP

Article ID: AG-VO5-I12-26

¹Bavya, N., ^{2*}V. Krishnan, ²V. Kanthaswamy, ²M. S. Marichamy, and ³B. Bavithra¹PG Scholar, ²Faculty, & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Wild musk melon, botanically called *Cucumis callosus*. ($2n = 24$), belonging to Cucurbitaceae family is one of the edible plants from Tamil Nadu. Traditionally, this plant was used as diabetic diet (leaves of with *Momordica charantia* leaves). This aromatic plant is normally widespread in countryside and seaside areas. This aromatic plant is commonly called as Wild musk melon, Kachri and Small guard

ORIGIN AND DISTRIBUTION

This wild species is originated from India and adjacent countries. Though it is widely used for medicinal purposes in Asia and Tropical Africa.

BOTANICAL DESCRIPTION

It is a perennial climber; stems 1.0-1.5 m, slender, angular, rough with short, rigid hairs. Leaves alternate, 3-6 cm long, suborbicular, base cordate, palmately 5-7 lobed, lobes round or ovate-oblong, often narrowed at the base, apex round, dentate or lobulate; petioles 2-6 cm long, slender, hispid. Plants are monoecious. Male flowers often solitary; peduncles 0.5-1.0 cm long; calyx-tube narrow campanulate, 3 mm long; lobes subulate, 1.5-2.0 mm long; corolla yellow, 6-7 mm long, lobes ovate, oblong, acute; staminal filaments short; anthers ca. 2 mm long, appendage of the connective shorter than anthers; pistillode 1 mm long. Female flowers: peduncles 2-3 cm long; ovary densely hairy; style 1.5-2.0 mm long; stigmas converge and 2.5 mm long. Fruits obovoid; seeds 5 x 2 mm, 1 mm thick, oblong and white.

FLORAL BIOLOGY

The blooms are small, yellow, and unisexual, with 5 petals and 3-5 stamens (male) or 3-5 stigmas. Monoecious, with distinct male and female blooms on the same plant. Clusters form at the plant's base. Have a short peduncle and a tiny bell-shaped corolla. It contains 3-5 stamens with yellow anthers. Male flowers often undergo anthesis between 5:00 and 7:00 a.m. Female flowers often undergo anthesis between 7:00 and 10:00 a.m. Peak anthesis time is approximately 8:00-9:00 a.m.



RELATED SPECIES

1. ***Cucumis trigonus***: The most common species found in India and Africa. The fruit has a distinctive horn shape, with three prominent ridges or horns on its surface of the fruit. Size of the fruit is (5-10cm) in length.
2. ***Cucumius prophetarum***: It is also called wild cucumber or prophets cucumber. The most common species found in India. Southeast Asia and Parts of Africa. The fruit is small to medium sized, typically around 5-15cm in length, with a cylindrical or oval shape
3. ***Cucumis melo agrestis***: Wilder melon cultivars, with smooth skin, and tart or bland taste. Often confused with cucumber.

MEDICINAL USES

The seeds are cooling and astringent and useful in bilious disorder, diabetics, easy bowel syndrome, stomach pain, vomiting, and constipation. The fruit is useful in jaundice, dropsy, fever, worms. The root is given in case of abdominal enlargement, cough, asthma, inflammation of the breast, ulcers, urinary diseases, and rheumatism. Tripalmitin is a triglyceride derived from palmitic acid that is used to manufacture soap. The dry fruits are traditionally used as folk remedy to treat conditions like urethral irritations, urine stoppage or dribbling and other urinary ailments of human in North-west India.

USES

Bhaji, Pickle, Chutney, Kheer mix, Sweets, Confectionery, Jam, Jelly, Candies, Cookies, Chokolets, Namkeen, Snacks, Chikki, Leather, Oil, Chips, Ice cream, dried-peel-roots-kachri fruit pulp, amchur, functional foods, etc.

COMMERCIAL VARIETIES

- 1. AHK-119:** Released by ICAR-CIAH, Bikaner. Fruits are small, egg shaped weighing 50-60 g. Fruits are ready for picking in 68-70 days after sowing, 22 fruits per vine, and yields of 9.5-10 t/ha
- 2. AHK-200:** The fruits are 100-120 g in weight, become ready for harvest in 65-67 days after sowing, bears about 20 fruits per vine and yield of 115-120 q/ha.
- 3. AHC-2:** Very early maturing variety bearing uniform, medium long fruits. Fruits are light green skin without furrows. Harvesting of tender fruits can be done 8-12 days after fertilization for salad or for garnishing vegetables. Fruits become ready for harvest in 53-55 days after sowing and harvesting continues up to 95-110 days. Fruits weighing 275-300g are suitable for slicing when their length is 30-35 cm and diameter is 3.0-3.5 cm. The flesh is crisp textured. Solid and 1.4-1.5 cm thick. About 12-15 tender fruits can be harvested giving a yield of 4 kg vine⁻¹ and 175-202 q/ha under arid situations.
- 4. AHC-13:** Very early and highly productive variety with profuse hermaphrodite flowers. For slicing, the fruits can be harvested at very early stage (3-6 days after fertilization). First harvest can be obtained 50 days after sowing and harvesting continue up to 95-100 days. About 20-25 fruits vine⁻¹ are borne. The tender fruits weighing 75-110 g are harvested when the length is 5.5-7.0 cm and diameters are 4.4-5.0 cm. The flesh is crispy and tasty which is about 1.0 cm in thickness. On an average 2.15 kg tender fruits can be harvested per vine giving a yield of 85-125 q ha⁻¹ and high heat tolerance.

CLIMATE AND SOIL

Kachri can be cultivated successfully both during rainy and spring- summer season. It requires warm and dry weather with plenty of sunshine for its growth and production. The optimum temperature for seed germination is 20-22°C whereas, 32-38°C is optimum for vegetative growth and fruit setting. It can be grown in variety of soils sandy loamy to heavy soil. Loamy soil rich in organic matter, pH ranging from 6-7 is best suited

FIELD PREPARATION

It requires well pulverized weed free land with 25-30 t. ha⁻¹ FYM.

PROPAGATION TECHNIQUES

Vegetative methods of propagation are used for multiplication of plants. Propagation of plant through vegetative methods viz. stem cutting, layering, stooling and grafting have been described for many arid fruit plants Treatment of seeds with growth regulators (GA₃) enhanced per cent seed germination and growth of seedlings

METHOD OF SOWING

Seed rate of 2-2.5 kg per ha. Pit (5 holes / pit and 2-3 seeds / hole at 2-3 cm depth), 2.5 m broad bed keeping seed spacing 50-60 cm within and 120-200 cm between rows. Alternatively, Seedlings are raised in polythene bags or in soil blocks and transplanted to the field when 4 weeks old. Now, low tunnel and poly house protective cover methods are also popular for off season production.

INTERCULTURAL OPERATION

FERTILIZER REQUIREMENT

About 50% recommended dose of NPK (40 kg N+20 kg of P₂O₅ +20 K₂O) along with 15 t/ha FYM (in channel) gave higher yield (113.08 q/ha).

IRRIGATION AND WEEDING

Irrigate the plants regularly, keeping the soil consistently moist but not waterlogged. Use drip irrigation or a soaker hose to provide even watering and reduce the risk of fungal diseases. Keep the area around the plants free from weeds to reduce competition for nutrients and water. Mulch the soil with organic materials like straw or grass clippings to suppress weeds and retain moisture.

HARVESTING

Kachri is ready for harvest about 70-80 days after sowing. The fruits should be firm and

their colour should change from green to a yellowish hue. Harvest starts after 45-50 days of sowing when seeds are soft and fruits are green. Sharp knife is used to harvest. For seed purpose, when fruits are of brown colour. Pulp is taken out and kept in water for 3-5 days. Seeds are rubbed and separated and dried to 6% moisture content. Average yield is 8–10 t/ha in 10-12 harvestings and seed Yield - 100-300 kg/ha.

PHYSIOLOGICAL DISORDER & CONTROL MEASURES

- 1. Bitterness:** Caused due to stress, nutrient imbalance, or genetic factors. Control measure by maintaining optimal growing conditions, ensure balanced nutrition, and select suitable varieties.
- 2. Spongy Tissue:** Caused by water stress, heat, or nutrient deficiencies. Control measure is to regulate irrigation, provide shade, and maintain adequate nutrient levels.
- 3. Flesh Breakdown:** Caused by over-ripening, heat, or physical damage. Control measure is to harvest at optimal stage, handle carefully, and store properly
- 4. Rind Pitting:** Caused by water stress, heat, or nutrient deficiencies. Control measure by regulating irrigation, providing shade, and maintaining adequate nutrient levels.
- 5. Fruit Cracking:** Caused by rapid growth, water stress, or physical damage. Control measure by regulating irrigation, providing support, and handling carefully.
- 6. Yellowing:** Caused by nutrient deficiencies, water stress, or senescence. Control by maintaining adequate nutrient levels, regulating irrigation, and harvesting at optimal stage.
- 7. Sunscald:** Caused by intense sunlight, heat, or lack of shading. Control measure is to provide shading, use mulch, and regulate irrigation.

POST- HARVEST MANAGEMENT PRACTICES

Effective post-harvest management measures are critical for preserving the quality and prolonging the shelf life of Kachri.

- 1. Harvesting:** Kachri should be collected when the fruits are mature but firm. Overripe fruits may lose their texture and be unsuitable for preparation. Harvesting should take place early in the morning to avoid heat exposure, which can hasten deterioration. Choose fruits that are uniform in size and colour for harvesting, as they more suited to market demands.
- 2. Handling and Transportation:** Treat the fruits with care to avoid bruising or injuring the delicate skin, which can cause rot. To reduce handling damage, use soft gloves wherever possible.

3. Cleaning: After harvesting, wash the fruits with clean water to remove soil, dust, and pesticide residues. To limit microbial load, use a mild disinfectant, especially if the fruits will be processed.

4. Drying: After washing, the fruits should be dried in the shade to avoid sun damage and preserve their natural moisture balance. To prevent fungal diseases, proper drying is required before to storage.

5. Grading and Sorting: Sorting by Size and Quality: Arrange the fruits according to size, colour, and hardness. Grading helps to categorize goods for different markets or processing requirements.

6. Packaging: Choose breathable materials, such as perforated plastic bags, baskets, or cartons. This enables for air circulation, lowering the likelihood of moisture collection and deterioration.

7. Storage: This is of two types viz.,

i. Cool and Dry Storage: Keep Kachri in a cool, dry environment with a temperature between 10-15°C (50-59°F) and a relative humidity of 70-80%. These circumstances help to preserve the fruit's firmness and increase its shelf life.

ii. Short-Term Storage: Kachri is best consumed or processed shortly after harvest because its shelf life is less than that of other melons. Flavor and texture can be lost over long-term preservation.

8. Transportation: Use refrigerated trucks to maintain consistent temperature, especially for long journeys.

9. Marketing: Quick Marketing: Market the Kachri fruits as soon as possible after harvest to maintain their freshness and quality. Marketing delays might have a negative impact on quality.

10. Post-harvest Treatments: Fungal Control: The use of safe post-harvest fungicides can help to improve shelf life by reducing the frequency of fungal infections.

11. Processing: If the Kachri will be used to make pickles, chutneys, or powders, it is best to process it as soon as possible after harvesting to preserve the maximum flavour and nutritional content.

PEST MANAGEMENT

1. Fruit Rot (*Fusarium pallidorozeum*): Cause damage both quantitatively qualitatively. Control with the combination of carbendazim 12% + mancozeb 63% at 100, 300 and 500 ppm were found to be the most effective.

2. Red Pumpkin Beetle (*Aulacophora foveicollis*): Adults and larvae eat on Kachri leaves, stems, and flowers, causing defoliation and stunted growth. They burrow into the fruits, causing direct damage and rendering them unmarketable. Control measures include handpicking beetles and larvae to minimize their population. Infestations can be controlled by applying carbaryl or malathion at the proper levels.

DISEASE MANAGEMENT

1. Powdery mildew (*Podosphaera xanthii*): White, powdery fungal growth on the upper surfaces of leaves, stems and fruits. Infected leaves may curl, yellow, and die prematurely, limiting the plant's photosynthetic capacity. Effective control requires ongoing monitoring for early detection, use of sulphur-based fungicides or potassium bicarbonate as a preventative strategy and use resistant varieties if they are available.

2. Downy mildew (*Pseudoperonospora cubensis*): Yellow patches appear on the upper leaf surface, while a downy fungal growth develops on the underside. Severely infected leaves may die, leading to reduced yield. It is controlled by ensuring good air circulation by avoiding dense planting and keeping the field weed-free. Use fungicides such as Mancozeb or Chlorothalonil when the disease is first noticed.



MEDICINAL PROPERTIES OF TRADITIONAL RICE VARIETIES IN INDIA

Article ID: AG-VO5-I12-27**¹Padmavathi. K., Priyadharsan. D.S., Ashika. D.C., ²R. Vinoth and ³J. Gokulakrishnan**

¹ UG Scholar, B.Sc. (Hons) Agriculture, Institute of Agriculture (IOA), Tamil Nadu
Agricultural University, Kumulur, Trichy, Tamil Nadu

²Teaching Assistant (PBG), Institute of Agriculture (IOA), Tamil Nadu Agricultural University,
Kumulur, Trichy, Tamil Nadu

³Associate Professor (PBG), Institute of Agriculture (IOA), Tamil Nadu Agricultural University,
Kumulur, Trichy, Tamil Nadu

*Corresponding Author Email ID: padmavathikumar1512@gmail.com

Abstract

Traditional rice varieties in India are rich in bioactive compounds such as anthocyanins, phenolics, Y-oryzanol, minerals and dietary fibre, giving them notable nutritional and medicinal value. Unlike polished modern rice, these land races retain bran pigments and micronutrients that contribute to antioxidant, anti-inflammatory, glycemic- regulating and cardioprotective effects. Ethnobotanical practices across India also highlight their use in digestive care, coalescence diets and postpartum nourishment. Scientific studies increasingly support the superior antioxidant capacity and nutrient density of coloured and whole grain traditional rices, though clinical evidence remains limited. Promoting and conserving these varieties can enhance dietary diversity and public health while preserving India's agricultural heritage.

Key words

Traditional rice varieties; India; Medicinal properties; Functional foods; Anthocyanins; Polyphenols; Y- oryzanol; Antioxidant activity; Glycemic regulation; Ethnobotany; Nutrient-dense grains; Red rice; Black rice; Whole-grain rice; Public health nutrition; Bioactive compounds; Conserved landraces.

INTRODUCTION

India's agricultural heritage includes thousands of traditional rice landraces-locally adapted varieties cultivated and conserved by farmers for generation. Beyond the grain morphology, aroma and cultural value, many of these traditional rices contain concentrated micronutrients and phytochemicals that give them measurable functional and medicinal potential.

WHY TRADITIONAL RICE CAN BE MEDICINAL

Traditional Rice often retain bran, pigments and minor phytochemicals lost in highly polished, modern white rice. These compounds include:

- **ANTHOCYANIN & POLYPHENOLS** (in black/purple and red rice)- antioxidants, anti-inflammatory potential.
- **TOCOPHEROLS, γ-ORYZANOL & VITAMIN E**- lipid- protective and potential cholesterol-modulating activity.
- **HIGHER FIBRE AND LOWER GLYCEMIC INDEX**- in some landraces – useful in blood-sugar regulation and satiety (beneficial for diabetics/ weight management).

REPORTED MEDICINAL USES (BY CONDITION)- WHAT STUDIES & ETHNOBOTANY

1. **Antioxidant/anti-inflammatory / anticancer potential** - Coloured rices (black, purple, red) show high antioxidant capacity and are associated in lab studies with anti-proliferative effects on some cancer cell lines – attributes to anthocyanins and phenolics.
2. **Antidiabetic & glycemic control** – Many traditional landraces have lower glycemic responses and higher fibre; ethnobotanical reports and small biochemical studies suggest benefits for glycemic regulation when
3. **Cardiovascular support** – γ-Oryzanol, tocopherols and soluble fibre present in whole-grain traditional rice have been linked to cholesterol-modulating and cardioprotective actions in nutrition studies.
4. **Digestive & pediatric uses** – Rice water, lightly cooked porridge (kanji, gruel) prepared from certain traditional varieties is used across India for diarrhea, indigestion and convalescence because it's easy on the gut and provides electrolytes and energy.
5. **Galactagogue & postpartum nutrition**- Some varieties are used to improve lactation and mother recovery after childbirth – often part of traditional postpartum diets.

6. **Skin and wound care (Topical uses in folk practice)**- Husk and sprouted-rice preparations historically appear in folk pharmacopeias for external soothing and for certain skin condition.

NOTABLE INDIAN TRADITIONAL RICE VARIETIES MENTIONED IN LITERATURE AND LOCAL PRACTICE;



❖ **BLACK / PURPLE RICE** (regional landraces)

Antioxidant rich (anthocyanins)



❖ **RED RICE** (e.g., many tribal/westernghats landraces)

Polyphenols, iron content.



- ❖ **Palakkadan matta** (kerala) – reputed for higher iron and distinct nutrient.



- ❖ **Kagga (Karnataka)** – high fibre, iron & zinc, traditional claims of slow digestibility.



- ❖ **Thuyamalli and other Tamil Nadu landraces** – recent biochemical screens show promising antioxidant / anticancer leads.

Thooyamalli Rice Benefits

Thooyamalli Traditional White Rice Variety.

Strengthens nervous system and immune System.

This Rice suits for all Age groups, prevents and cures diabetics.

It contains a Rich source of vitamins and Minerals.

It is good for skin and body.



- ❖ **Kavuni/kavuni-** type black rice – high anthocyanin content.

**CONSERVATION, VALUE CHAINS AND PUBLIC HEALTH IMPLICATION:**

Protecting traditional rice diversity is not only culture preservation; it is a public health and nutrition strategy. Integrating nutritionally superior landraces into modern markets (through GI protection, farmer producer organization and value-added products) can make functional rices accessible while providing farmers premium returns. Recent state and institutional efforts (KVKs, AAU, ICAR-NRRI) are evaluating, registering and promoting high-value traditional lines to bridge conservation with scale-appropriate cultivation.

CONCLUSION

Traditional Indian varieties are a rich, underutilized source of nutrition and bioactive compounds. When consumed as whole grains or used in traditional preparations, these landraces can contribute antioxidants, minerals and fibre that support digestive and metabolic health. Conservation, scientific validation and value-chain development are needed to fully harness their medicinal potential for public benefit.

REFERENCES

1. Kowsalya p., Sharanyakanth P.S., Mahendran R. (2022). Traditional rice varieties: A comprehensive review on its nutritional, medicinal, therapeutic and health benefit potential. Journal of food composition and analysis.
2. ICAR-NRRI. (2023). Traditional rice food – The Rich heritage of India (L. Das, ed.). ICAR-NRRI publication.
3. Pullaiah, T. (ed.) (2021). Ethnobotany of India (5-volume set.) Routledge/CRC Press.



4. Thilavech, T. (2025). Black rice (*Oryza sativa* L.) and its anthocyanins: mechanisms and health benefits. Food Production, Processing and Nutrition.
5. NRRI Research Bulletin. (2019). Rice varieties of NRRI: yield, quality, special traits and tolerances to stresses. ICAR-NRRI.



Volume: 05 Issue No: 12

LIMA BEAN-PROTEIN AND FIBRE RICH UNDERUTILIZED VEGETABLE CROP

Article ID: AG-VO5-I12-28**¹Bavithra, B., ^{2*}V. Krishnan, ²V. Kanthaswamy, ²M. S. Marichamy, and ³N. Bavya**¹Ph. D. Scholar, ²Faculty, ³PG Scholar & Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Lima bean, botanically called *Phaseolus lunatus* ($2n = 22$), belonging to Fabaceae family, is also called butter bean, Sieva bean, Double bean, Rangoon bean, Madagascar bean or Wax bean is regarded as a minor vegetable as well as a pulse crop. It is chiefly cultivated in Maharashtra and smaller extent in other northern states of India. In Tamil Nadu, it is cultivated to a very meagre extent. Butter beans are healthy beans and are considered on par with meat and as a protein substitute for vegetarian diet. It is found in humid, sub-humid and semiarid tropical climate as well as warm temperate climate. Lima beans sprouts, leaves, young pods and green seeds are edible and eaten as vegetables.

ORIGIN AND DISTRIBUTION

Lima bean has its origin in the Andean and Meso-American region. It is cultivated as far north as Canada, as far south of Argentina and is widespread in Asia, Africa, Europe and Australia and little enters international trade and production being primarily used for local consumption.

BOTANICAL DESCRIPTION

Annual Bush or pole type. Tap root with secondary and tertiary root system. Stem is slender, internodes elongate, which produce the secondary and tertiary branches. Leaves pinnately trifoliate, leaflets are ovate, pubescent. Inflorescence is a raceme. Flowers are medium sized, few in numbers, carried on short racemes. Flower colour ranges from white to yellow or bluish purple.

Calyx gamosepalous; corolla exerted with a recurved; standard wings. The keel is characteristically spirally coiled around stamens and pistils. Stamens diadelphous (9+1). Ovary sessile with many ovules. The style is enclosed inside the keel and bearded with oblique stigma. Fruit an oblong-falcate legume in the form of a half-moon, flattened, puberulent with uncinete hairs or glabrescent, dehiscent by valves opening in a spiral way, 2–4 seeds. Seeds reniform, flattened, approximately 7 mm long, reddish brown, with dark spots



RELATED SPECIES

1. ***Phaseolus vulgaris***: Common bean, also known as the kidney bean, black bean, pinto bean, and many other varieties. This is one of the most widely cultivated and consumed bean species.
2. ***Phaseolus coccineu***: Scarlet runner bean, known for its striking red flowers and edible seeds.
3. ***Phaseolus acutifolius***: Tepary bean, a drought-resistant bean native to the southwestern United States and Mexico.
4. ***Phaseolus polyanthus***: Also known as the Mayo Coba or Peruvian bean, grown primarily in Central and South America.

CULTIVATED TYPES OF LIMA BEAN

1. Bush type cultivars: Determinate, matures earlier than pole type cultivars. The pods are 15 cm long, with mature seeds 1-3 cm long and oval to kidney shaped.



Bush type lima bean



Pole type lima bean

2. Pole type cultivars: Indeterminate types ranging from 1 to 15 meters in height. They grow slowly, but give a very good yield per square foot, but susceptible to different diseases.

USES OF LIMA BEAN

Lima beans are generally served as a side dish in conjunction with meats, starches and other vegetables. Lima bean is used to prepare soups, salads and stews. Lima bean is a good source of vegetable protein. It is a good source of Magnesium, Manganese and Copper. Lima bean is rich in soluble and insoluble fibre that reduce irritable bowel.

NUTRIENT COMPOSITION OF LIMA BEAN

i. Immature pod and seed: Contains carbohydrates 40 %, protein 11.5 %, fat 0.5 %, dietary fibre 9.2 %, sugar 2.8 %, Vitamin C 17 mg, folic acid 44.2 mcg, Vitamin E 0.18 mg, Vitamin K 2 mcg, Vitamin B1 0.3 mg, Mg 125 mg, Fe 4.2 mg, K 10.5 mg, Mn 0.516 mg, Zinc 0.98 mg and Na 2 mg. Immature lima bean vegetable has a low glycaemic index of 46.

ii. Mature seeds: Contain Carbohydrates 21 %, protein 7.5 %, dietary fibre 6.5 %, fat 6.8 %, Vitamin B1 0.142 mg, Folic acid 73 mcg, Fe 2.23 mg, Mg 40 mg, K 472 mg, Se 4.2 mcg and Zinc 0.86 mg. Seeds of lima bean contains Isoflavones such as genistein and daidzein that have protection role against breast cancer; phytosterols such as beta sitosterol that lowers blood cholesterol levels in the body.

TOXICITY

Except white seeded types all lima beans seeds contain hydrocyanic acid, glycoside

linamarin. To avoid toxic effect the seeds are to be soaked in water overnight and to be boiled before consumption. The boiled water must be drained.

COMMERCIAL VARIETIES

I. Bush type varieties

- 1. Cangreen (Thorogreen):** It matures in 68 days. This variety is for fresh market processing. The seed size is small and flat and light green in colour.
- 2. Dixie Butter pea Speckled:** It matures in 75 days. This variety is for fresh market processing. It is tolerant to heat. The seed size is small, nearly round and carmine speckled.
- 3. Dixie Butter pea white:** It matures in 75 days. This variety is for fresh market processing. It is less tolerant to heat than Dixie Butter pea Speckled. The seed size is small, nearly round and carmine speckled.
- 4. Fordhook 242:** It matures in 72 days. This variety is for fresh market processing. It is heat tolerant. The seed size is large, flat and medium green.
- 5. Eastland:** It matures in 70 days. This variety is for fresh market. The seed is flat and light green.
- 6. Henderson Bush:** It matures in 65 days. This variety is for fresh market. The seed size is small, flat and white in colour.
- 7. Jackson Wonder:** It matures in 65 days. It is suitable for fresh market processing. The seed size is small, flat and buff with dark mottled. ★ ★ ★ ★

II. Pole type varieties

- 1. Florida Butter Speckled (Calico):** It matures in 80 days and is suitable for fresh market. The seed size is small, flat and buff, splashed with maroon colour.
- 2. Sieva (Carolina):** It matures in 80 days and is suitable for fresh market. The seed size is small, flat and white in colour.

CLIMATE AND SOIL

Optimum temperature: 15-16°C. Large seeded varieties are adopted to lower temperature and lower humidity than small seeded types. It is suitable to grow in light loam soil, but also grown in clayey soil. Grown twice in a year: Rainy season, Spring season.

SPACING AND SOWING

Spacing for Pole or semi pole type varieties: 60 x 40 cm; and for Bush type: 35 x 45 cm. Propagation through Seeds. Seed rate for small seeded variety is 20 -35 kg/ha and for large

seeded 45-60 kg/ha. Seed germination temperature: 15°C - 20°C.

LAND PREPARATION

To prepare land for lima beans, select a sunny, well-drained site with loamy soil and a pH of 6.0 to 6.8. Clear debris, till the soil to 8-12 inches deep and incorporate organic matter for improved fertility. Test the soil and amend as needed, then level the surface. Plant seeds 1-2 inches deep, 2-4 inches apart, after the last frost when soil temperatures reach 60°F (15°C). Keep soil consistently moist, control weeds and monitor for pests and diseases. Harvest when pods are firm and full, or let them dry on the plant for dry beans.

FERTILIZER AND IRRIGATION

Manures and fertilizer FYM: 25 t/ha and NPK: 40:50:50 kg/ha. The crop requires frequent light irrigation. Over watering should be avoided.

INTERCULTURAL OPERATIONS

Light Hoeing: Use a hoe to gently cultivate the soil around the plants, breaking up crusts and aerating the soil. This helps improve root development and moisture retention while avoiding damage to the plants' roots.

Weeding: Regularly remove weeds that compete with lima beans for nutrients, water and light. Weeding can be done manually or with tools, ensuring you don't disturb the bean plants' roots.

Staking: For climbing or vining varieties, install stakes or trellises to support the plants. This helps keep them upright, improves air circulation, and prevents diseases.

MATURITY SYMPTOMS

i. Pod Appearance: The pods become plump, firm and often change colour from green to a yellowish or brownish hue, depending on the variety.

ii. Pod Texture: The pods should feel full and slightly swollen. If the beans inside are visible and have a mature, solid texture, it's a sign of readiness.

iii. Bean Colour: For dry beans, the seeds inside the pods should have reached their full colour and be firm. They should also rattle inside the pods when shaken.

iv. Leaf Condition: The plant's leaves may begin to yellow and die back, signalling that the plant is nearing the end of its growing cycle.

HARVESTING:

Harvesting of tender pods from 80 -90 days after sowing. Fully matured dried seeds are harvested for seeds purpose. Green tender pods – 5 to 10 t/ha.

Storage at 5°C to 7 °C at 90 % RH.



PHYSIOLOGICAL DISORDERS

- 1. Blossom Drop:** Flowers fall off before fruit sets, leading to poor pod development. This is rectified by ensuring good pollination by attracting pollinators with companion plants or by gently shaking plants to aid in pollen transfer and by maintain consistent moisture levels to avoid stress, as both drought and excessive water can affect flowering.
- 2. Pod Splitting:** Pods split open before or during harvest, often due to rapid changes in moisture or temperature. Remedial measure is to harvest pods promptly when they reach maturity to prevent splitting. Avoid extreme fluctuations in soil moisture. Maintain even watering practices.
- 3. Poor Seed Set:** Low number of seeds per pod or incomplete pod development. To improve seed set, adequate levels of phosphorus and potassium need to be applied, which are crucial for seed development. Avoid overcrowding to allow proper pollination and space for pod formation.
- 4. Leaf Curling:** Leaves curl upward or inward, possibly due to environmental stress or nutrient imbalances. Remedial measure is to have balanced nutrition to the crop. Regularly test soil and provide balanced fertilization to address deficiencies. Provide shade or windbreaks if excessive heat or wind is causing stress.

POST HARVEST MANAGEMENT

Smaller beans are blanched at 200° F for 2.5 to 3 minutes. More mature beans are blanched 4 to 5 minutes at 190°F to prevent bursting of the skins. The beans then spread in thin layers on drying trays and stir occasionally during the drying process. Normally the drying process started at 120 °F and 130 °F raise this temperature gradually to 150°F. They are then

washed and inspected for foreign material and then frozen individually and packaged in plastic pouches.

PEST MANAGEMENT

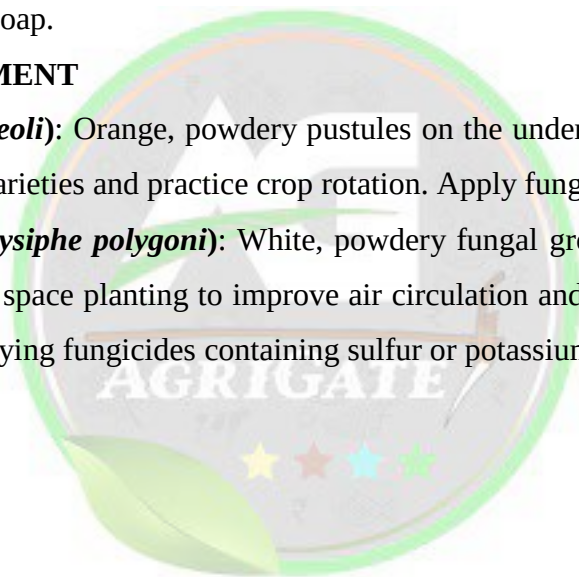
1. Aphids: Distorted growth, sticky residue (honeydew) on leaves, and presence of ants. Management by cultural method like keeping plants healthy and removing weeds that can harbor aphids. Biologically by introducing natural predators like ladybugs or lacewings. Chemical control by use of insecticidal soap or neem oil if infestations are severe.

2. Spider Mites: Fine webbing on the undersides of leaves, leaf stippling, and leaf drop. Cultural management by regularly watering the plants to reduce dust and maintain humidity. Biologically introduction of predatory mites or spider mite predators. Chemically we can control by use of miticides or insecticidal soap.

DISEASES MANAGEMENT

1. Rust (*Uromyces phaseoli*): Orange, powdery pustules on the undersides of leaves, leading to leaf drop. Use resistant varieties and practice crop rotation. Apply fungicides if rust is present.

2. Powdery Mildew (*Erysiphe polygoni*): White, powdery fungal growth on leaves and stems. Cultural management by space planting to improve air circulation and avoid overhead watering. Chemical control by applying fungicides containing sulfur or potassium bicarbonate.



WEED MANAGEMENT IN ORGANIC FARMING

Article ID: AG-VO5-I12-29**Purushothaman. N¹, Gokul .M², Sree Dhanush. Y², Madhumitha .R² and Anuja. R²**¹Assistant professor, Department of Agronomy, ²III B.Sc. (Hons.) Agriculture,

Imayam Institute of Agriculture and Technology –Kannanur – Trichy, Tamil Nadu, India

*Corresponding Author Email ID: puruag@gmail.com

Abstract

This paper on Weed Management in Organic Farming provides a comprehensive overview of the challenges and opportunities faced by organic farmers in controlling weeds without the use of synthetic herbicides. It emphasizes the importance of integrated weed management (IWM) strategies, combining traditional practices with modern innovations to promote sustainability and ecological balance.

Introduction

1. Importance of Weed Management in Organic Farming:

- Weeds are a major challenge in organic systems because they compete with crops for vital resources (water, nutrients, sunlight).
- Organic farming bans the use of synthetic herbicides, making weed control more difficult, labor-intensive, and reliant on non-chemical methods.

2. Ecological and Sustainable Weed Management:

- The primary aim is not the complete eradication of weeds but to keep their populations below economically damaging levels.
- Principles such as **prevention, ecological balance, soil health, and threshold-based management** guide organic weed control.

3. Methods of Weed Management:

- **Preventive Methods:** Clean seeds, proper manure management, and equipment sanitation to avoid weed spread.

- **Cultural Methods:** Crop rotation, cover crops, mulching, and stale seedbed techniques help suppress weeds.
- **Mechanical Methods:** Tillage, hand weeding, and mowing are widely used, though excessive tillage can harm soil health.
- **Thermal Methods:** Flaming, steam, or infrared radiation can kill weeds by causing cell rupture or by heating soil to sterilize weed seeds.
- **Biological Methods:** Natural processes like allelopathy (plants releasing chemicals to suppress weed growth) and the use of bio herbicides.
- **Emerging Technologies:** Robotics, laser weeding, and precision agriculture tools show promise for reducing labor intensity and improving precision.

4. Challenges:

- Labor intensity due to manual and mechanical methods.
- Yield losses during the transition from conventional to organic systems.
- Lack of affordable or accessible bio herbicides and limited farmer knowledge.
- Expensive emerging technologies, which can limit adoption, especially in developing countries.

5. Opportunities for Improvement:

- **Integration of Approaches:** Combining cultural, mechanical, biological, and technological methods to create sustainable, integrated systems.
- **Policy Support:** Government incentives can encourage organic farming practices and the adoption of innovative technologies.
- **Research & Education:** Focused research into bio herbicides, allelopathic crops, and improved farmer training programs could increase effectiveness.
- **Climate Resilience:** Organic farming methods that enhance soil health and biodiversity are better suited to withstand the impacts of climate change.

6. Regional Perspectives:

- In regions like India, organic weed management is being revisited as a sustainable alternative to chemical-based practices.
- In Europe and North America, automated tools and precision weed management techniques are becoming more widespread, though barriers such as high costs remain in developing countries.

Conclusion

Weed management in organic farming requires a holistic approach, emphasizing prevention, cultural practices, and a combination of mechanical, biological, and technological methods. While challenges such as labor intensity and yield reductions exist, innovations in precision agriculture and integrated strategies provide hope for more efficient and sustainable weed management solutions. Policy support, research, and the adoption of emerging technologies will play crucial roles in overcoming existing barriers and fostering long-term sustainability in organic agriculture.



Volume: 05 Issue No: 12

CHALLENGES, OPPORTUNITIES AND STRATEGIES FOR STRENGTHENING THE INDIAN SERICULTURE

Article ID: AG-VO5-I12-30

***Basavaraj Somalingappa Purad., Pavitra N., Padmapriya R., Lokesh Kumar P., Sabiya
Sultana M., Utchimahali T and Pavitra N**

Department of Sericulture, Forest College and Research Institute, TNAU, Mettupalayam
Tamil Nadu, India

*Corresponding Author Email ID: basavaraj.pgser2024@tnau.ac.in

Abstract

The Indian sericulture industry represents one of the country's oldest rural agro-industries, deeply interwoven with the social, cultural, and economic fabric of rural households. India is the world's second-largest producer of raw silk and the only country producing all commercially popular varieties of silk, including mulberry, Tasar, Muga, and Eri. Despite significant technological advancements and government interventions, the industry faces structural, economic, and environmental challenges that constrain its growth. Concurrently, shifting consumer preferences, the rising demand for natural fibres, and emerging biotechnological innovations present unprecedented opportunities for revitalization. This article critically examines the major challenges and potential opportunities for the Indian sericulture sector, drawing from historical trends, policy frameworks, technological developments, and market dynamics. It further suggests pathways for sustainable growth through modernization, skill development, and global integration.

Introduction

Sericulture is the art and science of silk production, has been practiced in India for over 2,500 years. It remains a crucial source of livelihood for millions of rural families, particularly small and marginal farmers, women, and tribal communities. The industry spans a comprehensive value chain that includes mulberry cultivation, silkworm rearing, cocoon production, reeling, twisting, weaving, dyeing, and garment manufacturing. Its labour-intensive

nature makes it ideally suited for employment generation in rural areas, aligning with India's goals of inclusive and sustainable development.

India's position as a major silk producer is supported by its diverse agro-climatic conditions, strong domestic demand, and extensive institutional backing from organizations such as the Central Silk Board (CSB). Yet, the industry faces stiff competition from synthetic fibres, declining profitability in certain regions, and periodic disease outbreaks in silkworm crops. In the global context, India competes with China, which dominates the international silk market through large-scale, mechanized, and technologically advanced production systems.

This article aims to provide an in-depth examination of the constraints and prospects shaping the development of the Indian sericulture industry. It analyses biological, economic, institutional, and environmental challenges and assesses emerging opportunities driven by market shifts and technological progress.

Historical Context and Economic Significance

The prominence of sericulture in India can be traced back to ancient trade routes such as the Silk Road, and archaeological evidence suggests silk use in the subcontinent since Harappan times; historically, Indian silk most notably Banarasi brocades, Kanchipuram silks, Assam Muga, and Bengal kantha has enjoyed international recognition for its aesthetic, technical, and cultural value, supported by regional weaving traditions, royal patronage, and organized production systems. Economically, sericulture holds special importance for several reasons such as;

- **Employment Generation**

The industry employs over 9 million people directly or indirectly, with a significant proportion being women. Its demand for semi-skilled labor makes it accessible to rural households.

- **Income Stability**

Sericulture provides year-round income, unlike seasonal agricultural activities.

- **Inclusive Growth**

Tribal communities in states such as Jharkhand, Odisha, and Chhattisgarh rely heavily on non-mulberry sericulture, especially Tasar and Eri.

- **Export Potential**

Silk fabrics and garments form a substantial part of India's handicraft and textile exports.

Despite these strengths, the industry's growth has been uneven due to structural vulnerabilities that require targeted attention.

Challenges in the Indian Sericulture Industry

I. Biological and Environmental Challenges

1. Pest and Disease Incidence

Silkworms are highly sensitive organisms, susceptible to viruses (Nuclear Polyhedrosis Virus, Cytoplasmic Polyhedrosis Virus), bacteria (flacherie), fungi (muscadine), and protozoa (pebrine). Disease outbreaks can result in massive losses in cocoon production.

2. Climate Sensitivity

Mulberry cultivation requires specific climatic conditions: moderate temperature, adequate rainfall, and sunlight. Irregular rainfall, drought, and rising temperatures due to climate change adversely impact leaf yield and quality.

3. Declining Soil Fertility

Continuous mulberry cultivation without proper crop rotation leads to soil nutrient depletion, affecting leaf quality and subsequently silkworm health.

II. Socioeconomic and Structural Challenges

1. Small Landholdings

Most sericulture farmers operate on marginal lands (0.25–1 acre). Limited land restricts mulberry cultivation and cocoon production capacity.

2. Labor-Intensive Procedures

Sericulture is highly labour-intensive, requiring meticulous daily attention. Urban migration of youth has caused labour shortages in several traditional sericulture regions.

3. Low Farmer Profitability

Cocoon prices fluctuate due to market volatility, inconsistent demand, and competition from imported silk. Farmer profits are often minimal after accounting for labour, feed, and disease management costs.

III. Technological Challenges

1. Slow Adoption of Improved Practice

Despite available technologies, adoption remains low such as High-yielding mulberry varieties, Disease-resistant silkworm breeds, Improved rearing houses,

Automatic reeling machines etc. High upfront costs and lack of technical training hinder widespread implementation.

2. Inadequate Infrastructure

Many rural areas lack drying chambers, rearing sheds, cold storage for eggs, and reliable electricity for reeling and weaving operations.

IV. Market and Global Competition Challenges

1. Competition from China

China's dominance stems from mechanized production, large-scale operations, and aggressive pricing strategies. Indian silk products often struggle to compete in cost-sensitive international markets.

2. Synthetic Fiber Competition

Cheaper synthetic alternatives like polyester, nylon, and rayon have reduced the demand for natural silk in mass markets.

3. Poor Marketing Networks

Silk farmers often rely on middlemen due to the absence of organized marketing systems. This results in low profits and limited bargaining power.

V. Policy and Institutional Challenges

1. Fragmented Supply Chain

Lack of integration between mulberry growers, silkworm rearers, reelers, and weavers leads to inefficiencies and quality inconsistencies.

2. Inconsistent Support Across States

State sericulture departments exhibit varying degrees of support, leading to uneven regional development.

3. Insufficient Research Translation

Although India has strong research institutions, their innovations often fail to reach farmers due to inadequate extension services.

Opportunities in the Indian Sericulture Industry

Despite its challenges, sericulture in India holds significant untapped potential: emerging technologies, growing global demand for sustainable fabrics, and supportive government initiatives together create a favourable environment for sectoral transformation. With targeted investments in research, value-addition, and market linkages, the industry can move up the value

chain from raw silk to high-margin biomedical, cosmetic, and technical applications. Expanding sericulture will generate rural employment, strengthen household incomes especially for women and diversify India's textile exports.

I. Increasing Global Demand for Natural Fibers

As global consumers shift toward eco-friendly and biodegradable textiles, natural fibres like silk are regaining prominence. Silk's unique properties like biodegradability, hypoallergenic nature, lustre, and thermal regulation make it as a premium sustainable fabric. India, being a diverse silk producer, is well-placed to meet this growing demand, especially in high-value markets such as Europe, Japan, and the United States.

II. Technological Advancements

1. Improved Mulberry Varieties

High-yielding V1, G2, G4 and drought-tolerant varieties such as S-1635 and Vishala increase leaf yield and enhance cocoon productivity.

2. Hybrid Silkworm Breeds

New breeds exhibit higher silk yield, better disease resistance and stability across seasons. These help reduce mortality and stabilize cocoon production.

3. Digital Technologies

Mobile-based advisories, IoT-enabled rearing houses, and AI-driven disease prediction models can greatly improve efficiency.

III. Expansion of Non-Mulberry Sericulture

Non-mulberry silks such as Eri, Tasar, and Muga offer unique opportunities. Eri silk is popular due to its "Ahimsa" (non-violent) nature. Tasar silk supports tribal communities and has high export potential. Muga silk, exclusive to Assam, has unmatched durability and natural golden sheen. These niche silks attract premium prices and have growing global demand in luxury and ethical fashion markets.

IV. Value Addition and Diversification

India can enhance profitability by focusing on silk-based cosmetics, sericin-based biomedical products, silk fiber composites, high-fashion garments, and home furnishings such as curtains, carpets, and upholstery, while advances in biotechnology open new avenues—most notably the use of silk fibroin for tissue engineering, wound healing, and drug delivery systems.

V. Employment and Women Empowerment

Sericulture offers substantial opportunities for women's empowerment because women handle over 60% of rearing and reeling tasks, it enables home-based employment, and government schemes increasingly target women's self-help groups, so expanding the sector supports inclusive development and strengthens rural economic resilience.

VI. Government Initiatives

Key programs include:

- Silk Samagra Scheme for holistic development
- Cluster Promotion Programme (CPP) to upgrade technology
- Skill development and extension services through CSB and state agencies
- Subsidies for rearing sheds, irrigation, and reeling equipment

If properly implemented, these initiatives can greatly strengthen the industry.

Strategies for Strengthening the Sericulture Sector

I. Enhancing Productivity through Technology

Boosting yields requires coordinated technology adoption: introduce improved mulberry varieties to raise leaf yield and nutritive value; deploy community cocoon dryers to reduce post-harvest losses and improve cocoon quality; install automatic reeling units at cluster level to increase filament recovery and reduce labour intensity; and pilot precision farming tools (soil testing, drip irrigation, remote sensing for pest alerts) to optimize inputs and lower costs. Public research institutions should validate varieties and equipment before scale-up to ensure local adaptability.

II. Strengthening Market Linkages

Create silk farmer cooperatives to aggregate supply, negotiate better prices, and access bulk inputs; promote direct procurement agreements between cooperatives and textile mills to shorten value chains and stabilize incomes; and develop digital marketing platforms for handloom clusters so artisans can reach niche buyers and traceability markets. Market aggregation and digital channels reduce middlemen and improve price discovery.

III. Improving Extension Services

Train agricultural extension personnel specifically for sericulture: pre-rearing preparation (mulberry nursery management), disease management (early detection and biosecurity), post-harvest processing (drying, grading), and market information dissemination (real-time

prices, buyer requirements). Strengthened extension improves adoption of best practices and links farmers to schemes and inputs.

IV. Promoting Organic and Sustainable Sericulture

Encourage organic mulberry cultivation and chemical-free rearing to access premium green-silk markets; pilot carbon-neutral production models (renewable energy for dryers, composting residues); and develop certification and branding for sustainably produced silk to capture higher margins. Certification should be supported by government or third-party auditors to build buyer trust.

V. Skill Development and Capacity Building

Address skill gaps across rearing, reeling, weaving, design, and quality control through modular training tied to market needs. Combine classroom instruction with on-farm apprenticeships and link trainees to placement or micro-enterprise support. Certification of skills helps mills and exporters identify qualified workers and raises overall product quality.

VI. Encouraging Public–Private Partnerships

Use PPPs to finance modern reeling equipment, establish quality testing laboratories, set up export-oriented production units, and fund R&D collaborations between industry and research institutes. Well-designed PPPs can accelerate technology transfer and create market-ready clusters; government schemes like Silk Samagra provide a policy framework to leverage such partnerships.

Future Prospects

With the increasing demand for sustainable luxury textiles, Indian silk has immense potential to reclaim global prominence. Innovations in biotechnology, sustainable agriculture, and digital technologies will reshape sericulture in the coming decades. Moreover, the global shift toward ethical fashion enhances opportunities for niche silks like Eri and Muga. However, the realization of these prospects requires coordinated efforts involving policymakers, researchers, farmers, entrepreneurs, and global buyers.

Conclusion

The Indian sericulture industry stands at a crossroads facing numerous challenges but also unparalleled opportunities. While disease incidence, climate variability, technological gaps, and competition from synthetic fibres create significant hurdles, emerging trends in sustainable textiles, global market expansion, and government initiatives offer renewed promise. By

prioritizing technological modernization, market integration, skill development, and sustainable practices, India can strengthen its position as a global leader in silk production. The industry's potential extends beyond traditional textile applications into biotechnology, high-performance materials, and eco-friendly innovations. A strategic and holistic approach can transform sericulture into a resilient, profitable, and future-ready sector, benefiting millions of rural households and contributing significantly to the national economy.

References

- Narasaiah, M. L. (2003). *Problems and Prospects of Sericulture*. Discovery Publishing House.
- Bharathi, D. (2016). Sericulture industry in India-A source of employment generation. *International Journal of Advanced Engineering Research and Science*, 3(10), 236881.
- Naik, A. H., Com, M., & NET, B. (2017). Sericulture Industry in India—An overview. *International research journal of commerce arts and science*, 8(9), 309-316.
- Sharma, K., & Kapoor, B. (2020). Sericulture as a profit-based industry—a review. *Indian journal of pure and Applied biosciences*, 8(4), 550-562.
- Mathur, A. K., Roy, S., & Mitra, J. (2013). Toward sustainable development of economic sub-sectors: case of Indian sericulture. *Journal of Security and Sustainability Issues*, 3(2), 15-30.
- Ssemugenze, B., Esimu, J., Nagasha, J., & Wandui Masiga, C. (2021). Sericulture: Agro-based industry for sustainable socio-economic development: A review.
- Upadhyay, A. P., & Barman, U. (2013). Identification of problems and formulation of extension strategies for upliftment of women agripreneurship in sericulture: An exploratory study in Garo hills of Meghalaya. *Journal of Academia and Industrial Research*, 2(6), 369-373.

Volume: 05 Issue No: 12

CUT FLOWER INDUSTRY EXPORT POTENTIAL AND PROBLEMS IN INDIA

Article ID: AG-VO5-I12-31**Dr A Malaisamy***

Professor and Head, Department of Agricultural Economics, Tamil Nadu Agricultural University
Coimbatore, Tamil Nadu, India

*Corresponding Author Email ID: malaisamy@tnau.ac.in

Introduction

In India, floriculture has undergone substantial increase in recent years. The National Horticulture Board (NHB, 2023) states that flowers are grown on an area of roughly 3.24 lakh hectares, yielding about 3.2 million tonnes of loose flowers and 9,000 million stems of cut flowers every year. The industry makes a significant contribution to exports; according to the Agricultural and Processed Food Products Export Development Authority (APEDA, 2023), India exported floriculture goods valued at ₹771 crore (USD 95 million) in 2022–2023. Major destinations are the USA (23%), Netherlands (18%), UK (12%), UAE (10%), and Germany (6%). As a source of revenue for small and marginal farmers, floriculture has become a significant subsector of agriculture. The Trade of Indian flowers in 2015 is Rs. 37,000 crores/ year. Nearly 77% of area under floricultural crops is concentrated in seven states encompassing Tamil Nadu, Karnataka, Andhra Pradesh, West Bengal, Maharashtra, Haryana, Uttar Pradesh and Delhi. Among diverse states, Tamil Nadu comes first in area followed by Karnataka, West Bengal and Andhra Pradesh.

The retail flower industry, estimated at ₹15,000 crore in 2023, is projected to grow at more than 12% annually, with online and app-based delivery services accounting for nearly 25% of the urban flower market by 2025

Production Trend over the years

The area at the beginning of 2014–15 was 246.13 thousand hectares (ha), which has increased significantly by 12.78% to 277.57 thousand ha in 2015–16, and then increased by

10.60% to 306.95 thousand ha in 2016–17. Subsequent years experienced different fluctuations, with peaks and decreases such as a dip to 282.38 thousand ha in 2021-22 (a 12.32% decrease from 2020-21) and a recovery to 296.74 thousand ha in 2023-24, showing a 4.26% increase from the preceding year.

The cultivation of loose flowers commenced at 1639.02 metric tons (MT) during the 2014-15 period. In the following years, production exhibited diverse trends: it rose by 1.05% to 1656.24 MT in 2015-16, increased further to 1699.57 MT in 2016-17 (a 2.63% rise), and continued its ascent, reaching 2284.46 MT in 2023-24, representing a 1.88% growth from the year before. Significantly, there were variations in production, such as a peak of 2323.44 MT in 2019-20, indicating a 2.66% increase from 2018-19, and a decline to 2151.96 MT in 2020-21, reflecting a decrease of 7.39% compared to the prior year. Despite these variations, the overall pattern in loose flower production over the decade demonstrates a consistent upward movement with occasional fluctuations.

Conversely, the output of cut flowers began at 105.35 MT during the 2014-15 period and experienced a substantial growth to 527.67 MT in 2015-16, reflecting an impressive 401.14% increase. The following years exhibited variations: cut flower production reached its highest point at 946.54 MT in 2023-24, which marked a 10.78% rise compared to the year before. There were significant fluctuations over the years, including a drop to 614.64 MT in 2021-22 (a 25.78% decline from 2020-21) and a rebound to 854.42 MT in 2022-23, indicating a 39.02% growth from the previous year.

Blending both loose and cut flowers, total output began at 1744.37 MT in 2014-15 and rose to 2183.91 MT in 2015-16, indicating a 25.22% growth. The overall production kept varying each year, hitting its highest point at 3231.01 MT in 2023-24, reflecting a 4.34% rise compared to the year before.

Cut flower Industry

The global cut flower industry is valued at around USD 40 billion, accounting for nearly 75% of the global floriculture trade. Roses dominate with nearly 40% share, followed by chrysanthemums, carnations, tulips, lilies, and orchids (FAO, 2022). The Netherlands continues to be the hub of international flower auctions, particularly through the Aalsmeer Flower Auction, which handles more than 12 billion flower stems annually

India has emerged as a significant supplier of roses, carnations, and orchids. In 2022-23, India exported about 6,500 metric tonnes of cut flowers, valued at approximately ₹458 crore (USD 56 million) (APEDA, 2023). Major export destinations for Indian cut flowers include USA (28%), Netherlands (19%), and Germany (7%).

Exports

India was the 26th highest exporter of cut flowers (out of 172) in the world in 2023, with \$28.9 million in exports. Cut flowers ranked 677th out of 1,212 Indian exports that year. Malaysia (\$7.63M), the United Arab Emirates (\$5.8M), Singapore (\$3.09M), the United Kingdom (\$1.47M), and Australia (\$1.01M) were India's top exporters of cut flowers in 2023. Between 2022 and 2023, Malaysia (\$3.51M), the United Arab Emirates (\$734k), and Nepal (\$434k) were the fastest-growing markets for Cut Flowers exports from India.

India exported 19677.89 metric tonnes of flowers to foreign nations in 2023–2024, valued at US\$86.63 million or INR 717.83 crores, according to flowers export data. India's cut flower exports have been increasing during the last three years and during 2021-22 there has been an increase of 54.87% vis-a-vis 2020-21. Tamil Nadu being the largest exporter of cut flowers among the States contributing 28.7% of the total share followed by Karnataka, Kerala, Maharashtra and West Bengal.

The total export value for the commodity category 0603 "Fresh, dried, dyed, bleached, impregnated, or otherwise processed cut flowers and flower buds suitable for bouquets or ornamental use" from India reached \$23 million in 2023. The sales of commodity category 0603 from India experienced an increase of 7.71% in comparison to 2022: the exports of the commodity category 0603 "Fresh, dried, dyed, bleached, impregnated, or otherwise processed cut flowers and flower buds suitable for bouquets or ornamental use" rose by \$1.7 million (the total exports of commodity category 0603 from India were \$22 million in 2022).

Top export destinations of "Cut flowers and flower buds of a kind suitable for bouquets or for ornamental purposes, fresh, dried, dyed, bleached, impregnated or otherwise prepared" from India in 2023:

- USA with a share of 16.7% (4 million US\$)
- Malaysia with a share of 15% (3.58 million US\$)
- United Arab Emirates with a share of 12.1% (2.91 million US\$)

- Singapore with a share of 11% (2.64 million US\$)
- United Kingdom with a share of 9.89% (2.36 million US\$)
- Netherlands with a share of 5.29% (1.26 million US\$)

Imports

In 2023, India imported \$2.99M of Cut Flowers, becoming the 77th greatest importer of Cut Flowers (out of 207) in the world. During the same year, Cut Flowers were the 1,012nd most imported product (out of 1,208) in India. In 2023, India imported Cut Flowers largely from: Thailand (\$1.33M), Nigeria (\$939k), Netherlands (\$331k), Kenya (\$102k), and China (\$97k). Between 2022 and 2023, Nigeria (\$713k), the Netherlands (\$95.2k), and Thailand (\$73.8k) were the countries from which India's imports of cut flowers grew the fastest.

The total worth of imported goods classified under group 0603 "Fresh, dried, dyed, bleached, impregnated, or otherwise treated cut flowers and flower buds suitable for bouquets or decorative uses" to India reached \$ 1.86 million in the year 2023. The import figures for commodity group 0603 to India experienced a 15.2% increase compared to the previous year: the imports of group 0603 "Cut flowers and flower buds of a kind suitable for bouquets or for ornamental purposes, fresh, dried, dyed, bleached, impregnated or otherwise prepared" rose by \$ 246 thousand (with the import value for group 0603 to India being \$1.61 million in 2022).

Top trading partners (import of "Cut flowers and flower buds of a kind suitable for bouquets or for ornamental purposes, fresh, dried, dyed, bleached, impregnated or otherwise prepared") of India in 2023:

- Thailand with a share of 72% (1.35 million US\$)
- Netherlands with a share of 13.7% (256 thousand US\$)
- Kenya with a share of 5.05% (94 thousand US\$)
- Colombia with a share of 3.96% (73 thousand US\$)
- China with a share of 2.69% (50 thousand US\$)
- South Africa - 15.9 thousand US\$

Tamil Nadu status in Flower industry:

In Tamil Nadu, loose flowers are cultivated over approximately 32,400 hectares, yielding a total production of 3,13,535 metric tons, which includes jasmine, chrysanthemum, marigold, rose, crossandra, and nerium. Additionally, cut flowers are grown in an area of 700 hectares,

resulting in an annual production of 12,900 metric tons of cut stems. Within this category, cut roses are cultivated on 600 hectares, producing 795 lakh stems (NHB, 2013). Jasmines, which are grown over 15,584 hectares and yield 1,42,397 tonnes, play a significant role in the floriculture industry. Tamil Nadu holds the top position among the flower-producing states in India, accounting for 25% of the nation's total flower production. The cultivation of cut flowers takes place in regions such as Hosur, Nilgiris, Kodaikanal (both upper and lower Palani hills), and Yercaud in the Shevroyan hills.

- **Tamil Nadu's flower markets**

Madurai has one of India's largest flower marketplaces. The primary flowers sold in this market are species of jasmine, rose, Crossandra, tuberose, Nerium, and others. The majority of the flowers sold at this market come from a 25-kilometer radius around the city.

- The only wholesale flower market in **Chennai** may be found at Parrys corner in the city's Central Market. Here, flowers including jasmine, tuberose, crossandra, roses, marigolds, and nerium are sold. Flowers are also imported from the markets in Madurai and Bengaluru, as well as from neighbouring manufacturing hubs including the districts of Dharmapuri, Panruti, Tambaram, and Poonamalei. About one half of the produce comes from local areas and the rest from Bengaluru and Madurai. The flowers are transported to this market by buses, trucks and air. ★ ★ ★ ★ ★

As on date a Primary Processing Centre for Flowers cum International Flower Auction Centre at Hosur, Krishnagiri District has been established by the State Govt. and handed over to Tamil Nadu State Agricultural Marketing Board (TNSAMB) for operation of the Auction center. Development of software and registration of flower growers & Traders is in progress. Once the unit becomes functional, the stakeholders can utilize it for cut post-harvest requirements.

Problems in Flower industry

Production Constraints

The flower industry in India remains primarily informal, with more than 85% of flower producers being small-scale and subsistence farmers (NHB, 2023). Seasonal changes lead to a decreased year-round availability of valuable cut flowers, including roses and orchids. Limited availability of high-quality planting materials, such as certified seeds and tissue culture plants, hinders overall productivity. Incidences of

pests and diseases, like powdery mildew affecting roses and leaf blight in marigolds, result in annual crop losses ranging from 15% to 20%.

Post-Harvest Losses

It is estimated that 25% to 40% of the total flower yield is lost after harvest due to poor handling practices, absence of pre-cooling facilities, and inadequate packaging (APEDA, 2023). For delicate flowers such as roses and gladiolus, ineffective cold chain management reduces their shelf life from the global standard of 10-12 days to merely 4-5 days in India. The lack of refrigerated transportation leads to a decline in flower freshness during prolonged domestic and international shipments. Currently, the packing and transportation of flowers from farms to retail venues is rather unscientific.

Market and Trade Issues

The domestic market is very divided and largely influenced by intermediaries, who take 30-40% of the retail price, resulting in minimal profits for farmers. The absence of structured flower auctions and wholesale outlets diminishes clarity when compared to the Dutch auction model.

On an international level, India confronts intense rivalry from countries such as Kenya, Ethiopia, and Colombia, which have developed logistical networks and trade partnerships with the EU and the USA. India holds a mere 0.6% of the world's floriculture export market, indicating challenges in competitiveness.

Environmental Challenges

The over-reliance on chemical fertilizers and pesticides in the cultivation of cut flowers harms both soil and water quality. A significant problem is water shortage, as flower varieties like roses necessitate as much as 8,000-10,000 cubic meters of water per hectare annually. Climate change (erratic rainfall, heatwaves, unseasonal frosts) increasingly disrupts flowering cycles and quality. Carbon footprint concerns are rising in export markets, with EU customers demanding eco-labelled and certified flowers.

Digital Marketing & E-Commerce

The Indian market for online flower delivery anticipated to expand at approximately 20% compound annual growth rate, fueled by services such as Ferns n Petals, FlowerAura, and BigBasket that are boosting demand. It is estimated that by the year 2025, about 25-30% of sales for flowers in urban areas will be conducted via online platforms.

Other challenges

- Insufficient information and the employment of outdated technology in India's floriculture sector.
- There is a lack of awareness about new cultivation methods and flower varieties among farmers in India. Consequently, they are missing out on the advantages of gardening for profit. Despite possessing a wide range of soil and climate conditions suitable for growing a variety of flowers, India accounts for only 0.6% of the global floriculture market.

Export Challenges and way Forward:

Despite having a rich and diverse production base, India's exports of floral products remain disappointing. This lack luster performance can be linked to several issues, such as the

- Limited availability of air cargo space in major airlines, as most carriers prefer to transport heavier loads. The current flight frequency during peak seasons falls short of what is necessary for exporting goods.
- Exporters face infrastructure challenges, including poor road conditions, insufficient refrigerated transport, and inadequate storage options.
- Moreover, the absence of professional services for logistics and support leads to higher technological costs for Indian exporters. To address these challenges, it is crucial to focus on lowering import duties on planting materials and equipment.
- Air freight charges need to be made more affordable. Airlines should ensure adequate cargo capacity through the establishment of exemplary nurseries that provide authentic planting materials. Local cooperative flower associations should be formed.
- Training institutes for diploma courses in floriculture, similar to ITI programs, ought to be established to prepare personnel for this sector.
- Exporters must develop and oversee effective quality control processes spanning from the production stage to post-harvest handling, storage, and transportation.
- An evaluation of the floriculture sector's strengths, weaknesses, and opportunities indicates that India possesses significant potential for exporting floral products. While the global floriculture market is expanding at a considerably higher rate than in India, opportunities exist to narrow the gap between demand and supply.

Volume: 05 Issue No: 12

SRI S. JAYAPAL REDDY: THE BIODIVERSITY GUARDIAN OF TELANGANA

Article ID: AG-VO5-I12-32**Esvaran.S***

B.Sc.(Hons.) Horticulture 3rd year, HC&RI, TNAU, COIMBATORE, India

*Corresponding Author Email ID: esvarans143@gmail.com

Introduction

In an era of continuous farming, monoculture, and industrial agriculture seeking rapid profits, only some visionary farmers work in harmony with nature. One such pioneering farmer is Sri S. Jayapal Reddy. He hails from Tallapoosapalli village in Kesamudram mandal, Mahabubabad district, Telangana state. With over forty years of experience, he stands as a role model in farming that protects nature and diverse life forms. His work truly embodies the meaning of the title "Guardian of Biodiversity."

Crop Diversity :

Jayapal Reddy's farm is a living repository of agricultural biodiversity. Unlike monoculture, he cultivates many food and horticultural crops on his 40-acre farm.

Main crops :

- Paddy: Telangana Sona (RNR 15048), KNM-1638
- Maize: DHM-117
- Pulses: Green gram (MGG-295, 351)
- Groundnut: Kadari-36, Girnar-4
- Turmeric: Rajapuri, Rajendira, Kasturi
- Chilli: LCA-334, LCA-625, Warangal Sabatta
- Mango orchard (6 acres): Banishan, Himayat, Dasher, Alphonso

Through these, he preserves both traditional and improved varieties, ensuring food security and income.

Integrated Livestock Farming :

He practices a closed ecological system with diverse livestock.

Livestock he maintains :

- 10 indigenous fowl breeds: Sagival, Gir, Ongole
- 6 buffaloes
- 200 cattle and 60 goats
- 50 chickens
- Fish farming in farm ponds and open wells

This system guarantees animal welfare, breed conservation, nutrient recycling, and steady income.

Natural Fertilizer :

Jayapal Reddy fully follows natural and traditional agronomic practices. Key fertilizers he uses include:

- Panchagavya, Jeevamrutham, Neemasthiram, Ganamrutham, Aknisthiram
- Azolla pits, vermicomposting, green fodder cultivation
- Crop rotation, intercropping, raised bed formation

These maintain soil microflora and ensure long-term sustainability.

Natural Pest Management :

Avoiding harmful chemical pesticides, he uses:

- Solar light traps
- Green manuring, trap crops, herbal mixtures
- Flowering plants and fence trees

These protect the beneficial insects and birds inhabiting the farm ecosystem.

Farmer Producer Organizations :

Not just a farmer, but also a guide and trainer.

- Established the Tallapoosapalli community
- Formed FPOs at mandal and district levels
- Member of the district ATMA committee
- Provides advice in WhatsApp groups
- Conducted natural farming training

Through these efforts, he helps other farmers learn biodiversity conservation.

Economic Success :

Proves that diversified farming can be profitable with an annual income of ₹20-22 lakhs.

Income sources:

- Crop sales (paddy, chilli, turmeric)
- Livestock products
- Fish farming
- Processed products

He aims to achieve ₹50 lakhs income through organic certification and value addition in future.

Awards and Recognitions :

- Best Farmer Award – PJTSAU (2021)
- Udyan Ratna Award (2020, 2021)
- Navonmesh Krushi Puraskar – ICAR-IARI (2018)
- Progressive Farmer Award – AIFA (2017)
- Recognized by various agricultural organizations
- Represented India at international agricultural conferences

Conclusion

Jayapal Reddy's farm is not just a production system — it is a biodiversity sanctuary. His commitment to protecting life forms and sustainable livelihoods makes him a true biodiversity guardian.

"My land is not just for crops; it is a place where life thrives — above and below." — S. Jayapal Reddy

MILLET READY TO RECONSTITUTE (RTR) MIX

Article ID: AG-VO5-I12-33***Er. V. Vidhya and Er. B. Hemalatha**

Assistant Professor, Department of Agricultural Engineering, Adhiyamaan College of
Agriculture and Research, Hosur.

Ph.D Scholar, Department of Processing and Food Engineering, TamilNadu Agriculture
University, Coimbatore. Tamil Nadu, India

*Corresponding Author Email ID: vidhyav6298@gmail.com

Abstract

The availability of millet-based products in the form of liquid is limited market and so, it is necessary to popularise the concept of milled based beverages in the millet era. Millet beverage in ready to reconstitute form might be easily acceptable by consumers. Also, it is high in nutritional composition. And the era is turning to millets from cereal based foods.

Keywords – Millet RTR.

Introduction

Growing awareness of the nutritional and ecological benefits of millets has increased the demand for diversified millet-based food products. However, the presence of millet beverages in the market is still minimal. This review highlights the potential of developing and popularizing millet beverages, particularly in RTR forms, as nutritious and convenient drink options.

Millet RTR development method

A ready-to-reconstitute little-millet smoothie was formulated by blending millet flour with fruit juices. The preparation process involved soaking the grains for 12 hours at room temperature, germinating them at 30 °C for 24 hours, and drying at 60 °C to reduce moisture below 12%. The grains were lightly roasted until a pleasant aroma developed, cooled, and dehulled to obtain malted grains. These were pressure-cooked for 10 minutes, cooled, and tray-dried again at 60 °C before being milled and sieved (105 µm) to produce malted, pre-gelatinized flour.

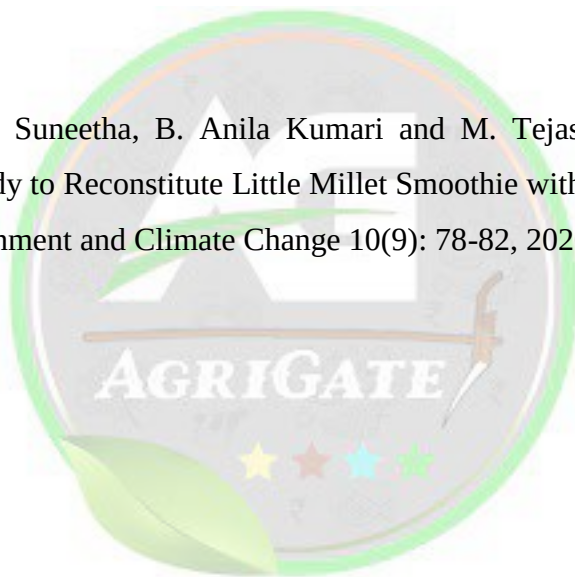
The flour was then mixed with milk powder and sugar in a 45:45:10 ratio and stored in airtight LDPE pouches. For reconstitution, the powder was diluted with water (1:1.5) and combined with fruit juice at 1:1 and 1:2 ratios. Sensory attributes—appearance, texture, flavour, taste, and overall acceptability—were evaluated by a semi-trained panel using a 9-point hedonic scale.

Conclusion

Millet-based RTR beverages represent a nutritious, plant-derived alternative to conventional flavoured drinks. Their market appeal can be enhanced through blending with fruit juices and purees, which improve both flavour and consumer acceptance. Continued innovation in formulation and sensory optimization can help position millet beverages as a mainstream healthy drink choice.

Reference

- B. Neeharika, W. Jessie Suneetha, B. Anila Kumari and M. Tejashree (2020) Organoleptic Properties of Ready to Reconstitute Little Millet Smoothie with Fruit Juices. International Journal of Environment and Climate Change 10(9): 78-82, 2020



Volume: 05 Issue No: 12

HOW FARMERS CAN TRAP CARBON IN THE SOIL BY NATURAL RECYCLING OF CROP RESIDUE

Article ID: AG-VO5-I12-34***Md Shahajahan¹, Bipul Barmon², Ashok Choudhury³ and Abhas Kumar Sinha⁴**

¹PhD Scholar, Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal-736165, India.

²PhD Scholar, Department of Seed Science and Technology, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal-736165, India.

³Director of Research, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal-736165, India.

⁴Head of the Department, Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal-736165, India.

*Corresponding Author Email ID: shahajahanmd023@gmail.com

Abstract

The natural recycling of crop residues is a vital approach for enhancing soil carbon sequestration and promoting sustainable agriculture. This practice involves retaining crop residues such as stalks, leaves, and stubble on the field after harvest, allowing them to decompose naturally and enrich the soil organic carbon (SOC) pool. Through processes like photosynthesis and microbial decomposition, carbon is transferred from the atmosphere into stable soil organic matter, mitigating climate change by reducing atmospheric CO₂ levels. Key agricultural practices supporting this process include no-till and conservation tillage, crop residue retention, integrated crop-livestock systems, cover cropping, and biochar application. These methods collectively improve soil health, fertility, and structure, enhance water retention and nutrient cycling, and boost crop productivity and also reducing soil erosion.

Key words: Carbon sequestration, residue, conservation tillage, cover crop, and biochar

Introduction

Rising temperatures and changing rainfall patterns are affecting crop cycles, especially in

regions growing rice and wheat. To manage tight planting schedules, farmers rely more on mechanized harvesting to save time. Combine harvesters leave large amounts of straw and stubble on the field. Removing or ploughing it back manually takes time and labour, both of which are in short supply. To clear fields rapidly before the next sowing, many farmers burn the residue, releasing carbon dioxide, methane, black carbon, and particulate matter. Farmers can significantly contribute to carbon sequestration in the soil through the natural recycling of crop residues, a practice that enhances soil health, mitigates climate change, and promotes sustainable agriculture (Siddique et al., 2024).

This approach leverages natural processes to return carbon to the soil, where it can be stored long-term, rather than being released into the atmosphere as carbon dioxide (Nazir et al., 2024). The core principle involves leaving **crop residues**- such as stalks, leaves, and stubble- on the field after harvest, allowing them to decompose naturally and integrate into the soil organic matter (Dadhich et al., 2021). The process of natural recycling of crop residues for carbon sequestration begins with photosynthesis, where plants capture atmospheric carbon dioxide (CO₂) and convert it into biomass (Pfeifer et al., 2024). A significant portion of this carbon is allocated to roots, which serve as a primary pathway for carbon entry into the soil organic carbon (SOC) pool. When crop residues are left on the field, they undergo decomposition by soil microorganisms, transforming into humus, a stable form of organic carbon (Hoffland et al., 2020). This process is crucial for long- term carbon storage in the soil.

Several agricultural practices facilitate the natural recycling of crop residues and enhance soil carbon sequestration the following are:

No-Till and Conservation Tillage: Traditional tillage practices disturb the soil, accelerating the decomposition of organic matter and releasing stored carbon into the atmosphere. No-till farming, where the soil is left undisturbed, and conservation tillage, which minimizes soil disturbance, significantly increase SOC sequestration, particularly in the surface layers (Kumar et al., 2020). These methods retain crop residues on the soil surface, protecting them from rapid decomposition and promoting carbon accumulation. Conservation agriculture (CA) practices, which often includes no-till, can sequester significant amounts of soil organic carbon.

Crop Residue Retention and Incorporation: Directly leaving crop residues on the soil surface or incorporating them into the topsoil layers is a fundamental strategy. This practice not only added organic carbon but also improves soil structure, water infiltration, and nutrient cycling.

The carbon sequestration rate generally increases with higher levels of crop residues. For instance, high residue levels can lead to sequestration rates of approximately 0.35- 0.40 Mg C ha⁻¹ year⁻¹, whereas conventional tillage or no-residue scenarios have much lower rates (Bana et al., 2023)

Integrated Crop-Livestock Systems (ICLS): Combining crop production with livestock grazing and tree integration can create more resilient and carbon-rich agricultural system. Animal manure and diversified plant biomass contribute to higher organic matter inputs, fostering greater carbon sequestration (Liu et al., 2023).

Cover Cropping and Crop Rotations: Utilizing cover crops during fallow periods prevents soil erosion and adds organic matter when incorporated into the soil. Diverse crop rotations, including legumes, can improve nitrogen cycling and overall soil health, thereby enhancing carbon storage. Legumes, through symbiotic nitrogen fixation, contribute to the nitrogen pool, which is essential for organic matter formation and stability.

Biochar Application: Biochar, produced from the pyrolysis of biomass like crop residues, is a stable form of carbon that can be added to soil. It significantly enhances soil organic carbon content, improves soil physical and chemical properties, and reduces greenhouse gas emissions. Biochar application can also improve nutrient retention and increase microbial survival, further supporting soil health and carbon sequestration (Oyebamiji et al., 2024).

Benefits of Soil Carbon Sequestration

Increasing soil carbon storage offers a multitude of benefits beyond climate change mitigation:

- **Improved Soil Health and Fertility:** Soil organic carbon is a key indicator of soil quality. Higher SOC improves soil structure, water-holding capacity, and nutrient availability, reducing reliance on synthetic fertilizers. Healthy soil supports a thriving microbial community, which plays a critical role in nutrient cycling and organic matter decomposition.
- **Enhanced Crop Productivity:** Improved soil health directly translates to better crop yields. The ability of soil to retain water and nutrients, coupled with a robust microbial ecosystem, supports stronger plant growth and productivity.
- **Reduced Soil Erosion:** Crop residues on the soil surface act as a protective layer, reducing the impact of rain and wind, thereby preventing soil erosion. This preserves the fertile topsoil and prevents degradation of agricultural lands.

Challenges and Considerations

While the benefits are substantial, challenges exist in implementing these practices widely. The rate and amount of SOC sequestration can vary significantly with soil types, depths, land use, and regional differences. For instance, the conversion of natural forest to agricultural land can influence SOC stocks. Economic factors, such as the costs of changing land management practices and the availability of incentives for farmers, also play a role. Policies that support sustainable farming, agriculture, and farmers are crucial for successful implementation

Conclusion

The natural recycling of crop residues presents a sustainable and effective strategy for enhancing soil carbon sequestration and combating climate change. By adopting practices such as no-till farming, residue retention, integrated crop-livestock systems, cover cropping, and biochar application, farmers can significantly increase soil organic carbon levels. These practices not only improve soil health and fertility but also boost crop productivity and reduce erosion.

Reference

- Bana, R. S., Bamboriya, S. D., Kumar, V., Godara, S., Gaydon, D. S., Laing, A. M., Dhakar, R., Shivay, Y. S., Meena, V. S., & Singh, D. (2023). Identifying optimum residue levels for stable crop and water productivity and carbon sequestration under a conservation agriculture based rice-wheat system. *Soil and Tillage Research*, 232, 105745. <https://doi.org/10.1016/j.still.2023.105745>
- Dadhich, S. K., Yadav, G. K., Yadav, K., Kumawat, C., & Munalia, M. K. (2021). Recycling of Crop Residues for Sustainable Soil Health Management: A Review. *International Journal of Plant & Soil Science*, 66–75. <https://doi.org/10.9734/ijpss/2021/v33i230528>.
- Hoffland, E., Kuyper, T. W., Comans, R. N. J., & Creamer, R. E. (2020). Eco-functionality of organic matter in soils. *Plant and Soil*, 455(1–2), 1–22. <https://doi.org/10.1007/s11104-020-04651-9>
- Kumar, A., Sharma, V., & Kumar, M. (2020). Soil carbon sequestration and greenhouse gas emission reductions under conservation agriculture: A review. In *Journal of Pharmacognosy and Phytochemistry* 9 (5), 2488-2493, 2020.

- Liu, L., Zheng, H., Liu, Z., Ma, Y.-Z., Han, H., & Ning, T. (2023). Crop – Livestock integration via maize straw recycling increased carbon sequestration and crop production in China. *Agricultural Systems*, 210, 103722. <https://doi.org/10.1016/j.agsy.2023.103722>
- Nazir, M. J., Li, G., Nazir, M. M., Zulfiqar, F., Siddique, K. H. M., Iqbal, B., & Du, D. (2024). Harnessing soil carbon sequestration to address climate change challenges in agriculture. *Soil and Tillage Research*, 237, 105959. <https://doi.org/10.1016/j.still.2023.105959>.
- Oyebamiji, Y. O., Adigun, B. A., Shamsudin, N. A. A., Ikmal, A. M., Salisu, M. A., Malike, F. A., & Lateef, A. A. (2024). Recent Advancements in Mitigating Abiotic Stresses in Crops. *Horticulturae*, 10(2), 156. <https://doi.org/10.3390/horticulturae10020156>
- Pfeifer, L., Helming, K., Schneider, H., & Ewert, F. (2024). Impact mapping tool for interdisciplinary research institutes. *Societal Impacts*, 3, 100048. <https://doi.org/10.1016/j.socimp.2024.100048>
- Siddique, K. H. M., Bolan, N., Rehman, A., & Farooq, M. (2024). Enhancing crop productivity for recarbonizing soil. *Soil and Tillage Research*, 235, 105863. <https://doi.org/10.1016/j.still.2023.105863>.



ROLE OF ADDITIVES TO CHEESE MILK

Article ID: AG-VO5-I12-35**Binod Kumar Bharti***

*Associate Professor, Department of Dairy Chemistry, Sanjay Gandhi Institute of Dairy Technology (Bihar Animal Sciences University) Patna

*Corresponding Author Email ID: bkbharti30@gmail.com

Abstract

Additives are widely used in food industries since the twentieth century to maintain the quality of food like smell, color, texture, etc. It prevents the food product from microbial spoilage. Food additives are increase the flavor, texture, emulsification, and stabilization of food at the time of manufacturing and processing of the product. Additives are categorized in many ways like preservatives, colorants, antioxidants, flavoring agents, emulsifying agents, antifoaming agents, stabilizers, etc., which are generally used in milk based products. Cheese is a fermented dairy products derived from milk that is produced in a wide range of flavour, texture and forms by coagulation of the milk protein by casein. In the manufacturing of cheese, various additives are used to improve the quality and shelf life.

Introduction

Additives are added to cheese milk to improve the flavor, texture, and appearance, and also increase the shelf life and nutritional value. Food additives play an important role in maintaining the physical and chemical properties of food such as color, smell, taste, and nutrition. Additives are also used to enhance the shelf life of many food products (Wu *et al.*, 2013a, b; Wang *et al.*, 2015). Cheese is a fermented dairy products derived from milk that is produced in a wide range of flavour, texture and forms by coagulation of the milk protein by casein. Cheese is a major dairy product worldwide, it is found in countless varieties and forms. In the manufacturing of cheese, various additives are used to improve the quality and shelf life. Additives like preservatives, stabilizers, and flavor enhancers help to consumer choices and also

assist cheese makers in creating high quality dairy products. Some common additives are used in cheese manufacturing process like calcium chloride, acidifiers, colour etc. Cheese additives calcium chloride is used to firm curds, acidifiers like citric acid to use for coagulating milk and annatto is used for coloring purpose. Other additives are also used for specific purposes, such as lipase to create piquant flavors or preservatives to prevent spoilage. In Edam, Gouda and swish cheese, it is necessary to add sodium or potassium nitrates to milk at 200 ppm, to control the blowing by butyric acid bacteria, *Clostridium botulinum*, and *Clostridium tyrobutyricum*. Nitrates do not affect the growth of lactic organism or coliform bacteria. During curing process of cheese, nitrates get converted to nitrites which may react under mild acidic conditions with various amines, amino acids and proteins to form nitrosamines that are carcinogens (WHO, 1978). Hydrogen Peroxide is an alternative treatment to full pasteurization, in some countries hydrogen peroxide is added (0.04-0.08%) treatment at 60°C for 16 sec in an HTST pasteurizer is given. The excess H₂O₂ is removed by addition of catalase enzyme. The treatment can reduce the number of bacteria, but spore formers are not destroyed (Scott, 1981).

Purpose of additives used in Cheese

Additives play an important role in cheese-making process. Natural cheese-making process involves transforming milk through fermentation, but the outcome can be unpredictable due to different factors such as moisture, bacteria and storage conditions. Additives help to standardize these factors and also ensure that cheese meets better quality and safety standards. Some of the important factors for using additives in cheese are discussed below:

- i. **Preventing spoilage:** Cheese additives can help to inhibit the growth of harmful bacteria and mold and also extending the shelf life of cheese.
- ii. **Enhancing flavor and texture:** Some cheese additives contribute to the desired flavor and consistency of specific types of cheese.
- iii. **Improving appearance:** Cheese colorants are added to make cheese for more appealing and also create a consistent appearance across batches.
- iv. **Maintaining safety:** Cheese additives ensure that cheese remains safe to eat over a longer period, which is especially important for products distributed widely and also stored for months.

Different Additives used in Cheese Milk

Additives are used for safety and keeping quality of cheese.

The use of additives is common practice on a global scale (Amin *et al.*, 2013; Cai and Liu, 2014). Some of the common additives and their specific roles in cheese are discussed below:

1. Texture and coagulation:

i. **Calcium Chloride:** It helps to firm the curds, especially in milk that has been weakened by heat or is low-fat. Calcium chloride added to pasteurized milk at a level of 0.02%. Some of the calcium of milk is heat precipitation as tricalcium phosphate and is not available for coagulation.

ii. **Acidifiers:** Mainly citric acid is used as acidifiers. It lowers the pH of milk help the proteins coagulate and also form curds. Acidifiers are essential for manufacturing of cheeses like ricotta and mozzarella.

iii. **Lipase:** Lipase enzyme produces sharp, piquant flavors and it is vital for cheeses like feta and parmesan cheese.

iv. **Stabilizers and emulsifiers:** It prevent fat and protein from separating the cheese and also help to create a smooth, consistent texture in processed cheeses and sauces. Stabilizers can help to maintain the texture, consistency, and mouthfeel of cheese, particularly in processed cheeses, spreads, and soft varieties of cheese. Starch, carrageenan, and guar gum are some common stabilizers are used in cheese. Starch is a polysaccharide which consists of a large number of glucose units and bonded together with the help of glycosidic bonds. Starch is basically composed of amylase and amylopectin, and these two polymers are linked into semi-crystalline granules which are highly hydrophilic and characterized by swelling properties (Agoda-Tandjawa *et al.*, 2017). Modified starch is added to shredded cheese to prevent clumping, ensuring that the cheese remains free-flowing and easy to sprinkle. In processed cheese spreads, starch enhances creaminess and also helps to maintain texture. Carrageenan is widely used as a thickener and gelling agent in food. In cheese, it helps retain the moisture and giving a smooth and creamy texture to spreads and soft cheeses. Carrageenan also provides structure and making processed cheese slices more durable and easier to handle. Guar Gum improves the consistency and stability of cheese, especially in low-fat varieties where achieving a creamy texture can be challenging. Guar gum also helps stabilize the moisture and preventing separation in cheese spreads.

v. **Starter Culture:** These are lactic acid bacteria that convert lactose to lactic acid. It is essential for cheese formation.

vi. **Rennet:** Rennet is an enzyme that coagulates milk, which is a crucial step in separating curds from whey. It is a complex set of [enzymes](#) produced in the stomachs of ruminant mammals. [Chymosin](#) is the key component of rennet. It is a [protease enzyme](#) that [curdles](#) the casein in milk. In addition to chymosin, rennet also contains other enzymes, such as [pepsin](#) and a [lipase](#)

2. Flavor and appearance:

i. **Colorant:** Mainly annatto and carmine are used as a colourant for manufacturing of cheese. Addition of food colorant to give cheese a more appealing and consistent appearance. Annatto colour is a pigment extracted from “the pericarp of the seed of *Bixa Orellana*.” It is a water-soluble compound that is yellow-orange color. Diapocarotenoids are the main color components in annatto. The methyl ester of a dibasic fatty acid forms the bixin pigment, which leads to the formation of hydrolyzed water-soluble norbixin on treatment with alkalis. Annatto is available in two types like bixin (oil extract) and norbixin (powdered form). Food colour is generally used to provide good quality, satisfy consumers, or assist marketing (Peira *et al.*, 2018; Teigiserova *et al.*, 2020).

ii. **Flavouring:** Different types of flavouring such as spices, herbs, and smoke are added to enhance the flavor of the cheese. Flavor Enhancers is one of the most critical aspects of cheese, and certain additives help to enhance it. Enzymes, starter cultures, and lipases are directly impact cheese flavor.

iii. **Enzymes:** Enzymes plays important roles in cheese. Mixtures of enzymes are accelerate the ripening process for aged of cheeses. Lipase enzymes break down fats and enhancing flavors in certain types of cheese. Lipases contribute to a stronger, more pungent taste in parmesan and feta cheese. Lipase is a popular additive for cheeses that need a richer and more intense flavor profile. Flavor enhancers are natural components of cheese-making, they are adjusted to produce consistent taste across the batches. It plays an important factor for commercial cheese making for maintains quality.

3.Preservation and safety:

i. **Antioxidant:** It prevents oxidation of cheese and prevent to spoilage of cheese. BHA and BHT antioxidants are added in cheese.

ii. **Preservation:** Preservation inhibit the growth of harmful bacteria and mold. It extending the shelf life of the cheese. There are two primary preservatives used in cheese are Natamycin

(E235) and Sorbic Acid Salts (E200, E202, E203). Natamycin (E235) is also known as pimaricin. It is a natural antifungal agent commonly used to prevent mold on hard and semi-hard cheeses. It is usually applied as a surface treatment, either by dipping or spraying the cheese. Natamycin inhibits mold growth on the cheese rind, which is especially beneficial for cheeses that require aging. Sorbic acid and its salts, including potassium and calcium sorbate, are used as preservatives that inhibit yeast and mold growth. These salts are applied to the surface of soft cheeses and spread to prevent spoilage, particularly in cheeses with a high moisture content. Sorbic acid salts dissolve in acidic environments. Sorbic acid is suitable for soft cheeses and they prevent spoilage without affecting taste or texture. Both Natamycin and sorbic acid salts provide an added layer of protection against spoilage, allowing cheeses to be stored safely in longer periods and in a wider range of conditions. Chemical preservatives are extensively used to manufacture and market food items in recent times (Davidson and Branen 2005).

iii. **Salts:** It helps to control microbial growth and also restore calcium balance.

4. Nutritional enhancement:

Vitamins and minerals are added in cheese to increase the nutritional value of the cheese.

Conclusion

Additives in cheese play an important role in enhancing its texture, flavor, appearance, and shelf life. Additives ensure that cheese products are safe, consistent, and high-quality, it is also suitable for widespread distribution and storage. Cheese additives like natamycin and sorbic acid salts help to prevent spoilage, carrageenan and guar gum stabilizers improve texture of processed cheese varieties. Flavor enhancers and colorants also contribute to the appeal and enjoyment of cheese. Citric acid is used as acidifiers. It lowers the pH of milk and helps the proteins coagulate and also form curds. Acidifiers are essential for manufacturing of cheeses like ricotta and mozzarella.

References

- Agoda-Tandjawa G, Le Garnec C, Boulenguer P, Gilles M, Langendorff V. Rheological behavior of starch/carrageenan/milk proteins mixed systems: role of each biopolymer type and chemical characteristics. *Food Hydrocoll.* 2017;73:300–312.
- Amin L, Azad M, Samian A. Factor influencing risk perception of food additives. *J Food Agric Environ.* 2013; 11:66–72.
- Cai W, Liu J. The improvement of the risk communication mechanism in food additives under

- the perspective of consumers' right to know. *J Food Saf.* 2014; 5:167–172
- Davidson PM, Branen AL. Food antimicrobial an introduction. *Food Sci Technol.* 2005; <https://doi.org/10.1201/9781420028737.ch1>
- Peira G, Bollani L, Giachino C, Bonadonna A. The management of unsold food in outdoormarket areas: food operators' behaviour and attitudes. *Sustainability.* 2028; 10(4):1180.
- Scott R. *Cheese Making Practice.* Applied Science Pub., London. 1981.
- Teigiserova DA, Hamelin L, Thomsen M. Towards transparent valorization of food surplus,waste and loss: clarifying definitions, food waste hierarchy, and role in the circular economy. *SciTotal Environ.* 2020; 706:136033
- Wang C, Wu J, Gao X. Basic attributives, functions and characteristics of food additives. *China Food Additives.* 2015; 10:154–158
- WHO. The World Health Organization (WHO) and UNICEF jointly convened the International Conference on Primary Health Care in Alma-Ata, USSR. 1978.
- Wu L, Zhang Q, Shan L, Chen Z. Identifying critical factors influencing the use of additives by food: enterprises in China. *Food Control.* 2013a; 31:425–432.



BIOACCUMULATION CAPACITY OF SEA URCHINS AS BIOMONITORS OF COASTAL POLLUTION

Article ID: AG-VO5-I12-36

S. Sakthi^{1*}, Dr. D. Manimekalai² A. Yamini³ and J. Musraf Sulaiman⁴

^{1,2,3,4} Department of Aquatic Environment and Management, Fisheries College and Research Institute, Thoothukudi, TamilNadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam, Tamil Nadu, India

*Corresponding Author Email ID: sakthi29062001@gmail.com

Abstract

Coastal ecosystems are increasingly impacted by pollutants from industrial, agricultural, and urban sources, highlighting the need for reliable biological indicators. Sea urchins serve as effective biomonitors due to their benthic lifestyle, non-selective grazing, and strong capacity to accumulate contaminants from sediments and seawater. This review outlines the mechanisms of pollutant uptake, including metal absorption, retention of hydrophobic organic compounds, and ingestion of microplastics. Key biomonitoring indicators-chemical concentrations, enzyme biomarkers, immune responses, spine damage, test thinning, and reproductive abnormalities—provide a comprehensive understanding of pollutant exposure and ecological risk. With rising anthropogenic pressures and emerging contaminants such as flame retardants and microplastics, sea urchin-based biomonitoring offers a sensitive, practical, and ecologically relevant tool for assessing coastal pollution and supporting sustainable marine ecosystem management.

Keywords: Biomonitor, POPs, Flame retardants, Echinodermata and Coelomic fluid

1. Introduction

Coastal ecosystems are increasingly exposed to a wide spectrum of pollutants originating from industrial discharge, urban runoff, agricultural activities, aquaculture effluents, shipping operations, and domestic sewage. These contaminants include heavy metals, persistent organic pollutants (POPs), hydrocarbons, pharmaceuticals, microplastics, and nutrient loads. Monitoring their ecological risks requires reliable sentinel organisms capable of reflecting changes in

environmental quality over time. Sea urchins (Phylum: Echinodermata; Class: Echinoidea) have emerged as valuable biomonitor organisms due to their ecological importance, high sensitivity to pollutants, benthic lifestyle and ability to bioaccumulate contaminants in tissues such as gonads, spines, and test (shell). With wide geographical distribution, ease of sampling and well-established biological endpoints, sea urchins are increasingly used in marine ecotoxicology and coastal pollution assessments.

2. Biological Basis for using Sea Urchins as Biomonitor Species

Sea urchins possess several physiological and ecological traits that make them suitable for environmental monitoring:

2.1 Benthic Feeding Behavior

Sea urchins exhibit a characteristic **benthic feeding** behavior, spending most of their life grazing on substrates at the seafloor. They feed on algae, seagrass detritus, biofilms, and organic-rich sediments using their specialized feeding apparatus, Aristotle's lantern, which allows them to scrape and ingest material from both hard and soft surfaces. Since pollutants such as heavy metals, hydrocarbons, pesticides, microplastics, and persistent organic pollutants (POPs) settle in bottom sediments, sea urchins are continuously exposed to these contaminants during feeding. Suspended particles released during storms, dredging, or coastal disturbances further enhance the presence of pollutants in their foraging zone. They also ingest epiphytic microalgae and detritus coated with adsorbed chemicals, increasing their overall exposure to sediment-bound contaminants. Their limited movement and relatively small home range make them strong reflectors of local contamination levels.

As non-selective grazers, sea urchins consume a mixture of organic and inorganic particles, including microplastics, nanoparticulates, and chemically contaminated sediments. This broad and continuous ingestion enhances their capacity to bioaccumulate a wide variety of pollutants. In turn, this feeding strategy allows sea urchins to mirror the bioavailable fraction of contaminants present in their habitat rather than just the total concentration present in water or sediments. These characteristics make them particularly valuable as biomonitors for assessing pollution gradients, identifying hotspot areas, and evaluating long-term contamination trends in marine and coastal ecosystems.

2.2 High Bioaccumulation Potential

Metals (Cu, Cd, Pb, Hg, Zn), pesticides, PAHs, PFAS, and organic flame retardants accumulate

in sea urchin tissues due to:

- Slow metabolic detoxification
- High lipid content in gonads
- Continuous grazing on contaminated substrates

2.3 Tissue Specificity

Different tissues show varying accumulation levels:

- **Gonads** – high accumulation of metals and organics
- **Test and spines** – long-term accumulation and structural deposition
- **Coelomic fluid** – rapid response to short-term exposure

This enables multi-tissue biomonitoring.

2.4 Sensitivity of Early Life Stages

Sea urchin embryos and larvae are widely used in toxicity testing due to their susceptibility to contaminants affecting:

- Fertilization
- Cleavage pattern
- Skeletogenesis
- Larval morphology



3. Mechanisms of Bioaccumulation in Sea Urchins

Bioaccumulation in sea urchins occurs through the processes of uptake, storage, and slow elimination of pollutants, making them highly effective indicators of environmental contamination. Metals enter sea urchin tissues through dermal absorption, ingestion of contaminated sediments and particles, and ion exchange within the coelomic fluid. Once inside, metallothionein-like proteins regulate and bind these metals, while excess quantities are stored long-term in the calcareous test and spines.

Organic contaminants such as PAHs, PCBs, and organophosphate flame retardants (OPFRs) are hydrophobic in nature and tend to accumulate in the lipid-rich gonadal tissues, where they persist and reflect prolonged exposure to pollution. Sea urchins also ingest microplastics, which can become trapped in the gastrointestinal tract, leading to oxidative stress, impaired digestion, and inflammatory responses. These particles may further adsorb other toxic chemicals, increasing their combined toxicity and amplifying the overall pollutant burden in sea urchins. Collectively, these mechanisms illustrate how sea urchins effectively accumulate a range of contaminants, making them reliable biomonitors for coastal environments.

4. Sea Urchin-Based Biomonitoring Indicators

Sea urchins offer a diverse set of measurable indicators that make them highly effective biomonitor species in coastal environments. Their tissues can accumulate pollutants, allowing the use of chemical indicators such as metal concentrations (mg/kg) in the gonads or test, levels of organophosphate flame retardants and polycyclic aromatic hydrocarbons (PAHs), and quantification of microplastic particles retained in the gastrointestinal tract.

In addition to chemical accumulation, a range of physiological indicators can be monitored, including changes in key detoxification enzymes such as GST, CAT, SOD, and lipid peroxidation (LPO), variations in coelomocyte counts reflecting immune response, and alterations in the gonadosomatic index (GSI) signalling reproductive stress. Structural changes also serve as important morphological indicators, including spine damage or malformation, thinning of the calcareous test, and deformities in embryos or larvae, all of which reflect exposure to chronic or acute contamination.

Furthermore, sea urchins exhibit sensitive reproductive indicators such as reduced fertilization success, delayed or abnormal embryonic development, and skeletal abnormalities in larvae, providing early warning signals of environmental degradation and pollutant stress. Collectively, these chemical, physiological, morphological, and reproductive endpoints make sea urchins a comprehensive and reliable tool for assessing coastal pollution and ecosystem health.

5. Applications in Coastal Pollution Assessment

5.1 Heavy Metal Pollution

Sea urchins accumulate high levels of Cd, Cu, and Pb in sediments near:

- Ports
- Industrial zones

- Mining-influenced coasts

Metal concentration in gonads reflects the bioavailable fraction in surrounding sediments.

5.2 Industrial & Urban Runoff

Organic contaminants such as flame retardants, PCBs, and PAHs accumulate in sea urchins from urbanized coasts, serving as indicators of industrial discharge.

5.3 Eutrophication and Sediment Disturbance

Dredging releases buried contaminants that are rapidly reflected in sea urchin tissues.

5.4 Climate Stress–Pollution Interactions

Studies show that ocean acidification increases metal bioavailability, enhancing accumulation in sea urchins—a critical consideration for future monitoring.

6. Advantages of Using Sea Urchins as Biomonitor Species

- Abundant and easy to collect
- Represent benthic contamination accurately
- High pollutant sensitivity
- Multi-tissue assessment options
- Well-established laboratory bioassays
- Low-cost monitoring compared to chemical sampling

7. Limitations of Sea Urchin Biomonitoring

- Species-specific accumulation differences
- Seasonal variation in gonad development affecting results
- Migration patterns may reduce location-specific accuracy
- Extreme pollution may cause mortality, reducing monitoring reliability
- Requires combined sediment and water analysis for interpretation

Conclusion

Sea urchins have proven to be exceptionally powerful biomonitor organisms due to their benthic lifestyle, non-selective feeding behavior, and strong capacity to accumulate a wide array of pollutants directly from sediment-rich coastal habitats, allowing them to reflect both the presence and intensity of environmental contamination. Their ability to retain heavy metals, organic pollutants, pharmaceuticals, and microplastics across multiple tissues—such as the gonads, test, spines, and coelomic fluid—provides insights into both short-term exposure and long-term ecological trends, while physiological, morphological, and reproductive biomarkers

serve as sensitive early-warning indicators of stress. As coastal ecosystems face increasing pressures from industrialization, urbanization, climate change, and newly emerging contaminants, sea urchin-based biomonitoring offers an integrative and ecologically meaningful tool for assessing pollution and its impacts. With their wide distribution, ease of sampling, and well-established bioassays, sea urchins contribute significantly to pollution assessment, coastal management, policy development, and long-term environmental stewardship.

References

- Bellas, J., & Paredes, E. (2014).** Sea-urchin fertilization bioassays for the assessment of marine pollution: A review. *Ecotoxicology and Environmental Safety*, 104, 284–293.
- Warnau, M., & Pagano, G. (2018).** Echinoids as bioindicators of marine pollution. *Environmental Toxicology and Chemistry*, 37(2), 338–352.
- ICES (International Council for the Exploration of the Sea). (2018).** *Techniques and methods for marine biomonitoring using invertebrates*. ICES Cooperative Research Report.
- Ferraro, M. V. M., & Fenocchio, A. S. (2014).** Echinoderms as model organisms in ecotoxicological studies. *Environmental Monitoring and Assessment*, 186, 5267–5280.
- Brothers, Christopher J., Harianto, John, and Byrne, Maria (2016).** Sea urchins in a high CO₂ world: Impacts of climate change on fertilization and early development. *Marine Environmental Research*, 113, 96–107.
- Díaz-Jaramillo, Mauricio, Valdés, Jorge, Silva, Rodrigo, and Barra, Ricardo (2017).** Sea urchins as bioindicators of coastal metal pollution: Bioaccumulation and biomarker responses. *Chemosphere*, 168, 349–360.

ROLE OF ADDITIVES TO CHEESE MILK

Article ID: AG-VO5-I12-37**Binod Kumar Bharti***

*Associate Professor, Department of Dairy Chemistry, Sanjay Gandhi Institute of Dairy Technology (Bihar Animal Sciences University) Patna, India

*Corresponding Author Email ID: bkbharti30@gmail.com

Abstract

Additives are widely used in food industries since the twentieth century to maintain the quality of food like smell, color, texture, etc. It prevents the food product from microbial spoilage. Food additives increase the flavor, texture, emulsification, and stabilization of food at the time of manufacturing and processing of the product. Additives are categorized in many ways like preservatives, colorants, antioxidants, flavoring agents, emulsifying agents, antifoaming agents, stabilizers, etc., which are generally used in milk based products. Cheese is a fermented dairy product derived from milk that is produced in a wide range of flavour, texture and forms by coagulation of the milk protein by casein. In the manufacturing of cheese, various additives are used to improve the quality and shelf life.

Introduction

Additives are added to cheese milk to improve the flavor, texture, and appearance, and also increase the shelf life and nutritional value. Food additives play an important role in maintaining the physical and chemical properties of food such as color, smell, taste, and nutrition. Additives are also used to enhance the shelf life of many food products (Wu *et al.*, 2013a, b; Wang *et al.*, 2015). Cheese is a fermented dairy product derived from milk that is produced in a wide range of flavour, texture and forms by coagulation of the milk protein by casein. Cheese is a major dairy product worldwide, it is found in countless varieties and forms. In the manufacturing of cheese, various additives are used to improve the quality and shelf life. Additives like preservatives, stabilizers, and flavor enhancers help to consumer choices and also assist cheese makers in creating high quality dairy products. Some common additives are used in

cheese manufacturing process like calcium chloride, acidifiers, colour etc. Cheese additives calcium chloride is used to firm curds, acidifiers like citric acid to use for coagulating milk and annatto is used for coloring purpose. Other additives are also used for specific purposes, such as lipase to create piquant flavors or preservatives to prevent spoilage. In Edam, Gouda and swiss cheese, it is necessary to add sodium or potassium nitrates to milk at 200 ppm, to control the blowing by butyric acid bacteria, *Clostridium botulinum*, and *Clostridium tyrobutyricum*. Nitrates do not affect the growth of lactic organism or coliform bacteria. During curing process of cheese, nitrates get converted to nitrites which may react under mild acidic conditions with various amines, amino acids and proteins to form nitrosamines that are carcinogens (WHO, 1978). Hydrogen Peroxide is an alternative treatment to full pasteurization, in some countries hydrogen peroxide is added (0.04-0.08%) treatment at 60°C for 16 sec in an HTST pasteurizer is given. The excess H₂O₂ is removed by addition of catalase enzyme. The treatment can reduce the number of bacteria, but spore formers are not destroyed (Scott, 1981).

Purpose of additives used in Cheese

Additives play an important role in cheese-making process. Natural cheese-making process involves transforming milk through fermentation, but the outcome can be unpredictable due to different factors such as moisture, bacteria and storage conditions. Additives help to standardize these factors and also ensure that cheese meets better quality and safety standards. Some of the important factors for using additives in cheese are discussed below:

- v. **Preventing spoilage:** Cheese additives can help to inhibit the growth of harmful bacteria and mold and also extending the shelf life of cheese.
- vi. **Enhancing flavor and texture:** Some cheese additives contribute to the desired flavor and consistency of specific types of cheese.
- vii. **Improving appearance:** Cheese colorants are added to make cheese for more appealing and also create a consistent appearance across batches.
- viii. **Maintaining safety:** Cheese additives ensure that cheese remains safe to eat over a longer period, which is especially important for products distributed widely and also stored for months.

Different Additives used in Cheese Milk

Additives are used for safety and keeping quality of cheese. The use of additives is common practice on a global scale (Amin *et al.*, 2013; Cai and Liu, 2014).

Some of the common additives and their specific roles in cheese are discussed below:

Texture and coagulation:

- i. **Calcium Chloride:** It helps to firm the curds, especially in milk that has been weakened by heat or is low-fat. Calcium chloride added to pasteurized milk at a level of 0.02%. Some of the calcium of milk is heat precipitation as tricalcium phosphate and is not available for coagulation.
- ii. **Acidifiers:** Mainly citric acid is used as acidifiers. It lowers the pH of milk help the proteins coagulate and also form curds. Acidifiers are essential for manufacturing of cheeses like ricotta and mozzarella.
- iii. **Lipase:** Lipase enzyme produces sharp, piquant flavors and it is vital for cheeses like feta and parmesan cheese.
- iv. **Stabilizers and emulsifiers:** It prevent fat and protein from separating the cheese and also help to create a smooth, consistent texture in processed cheeses and sauces. Stabilizers can help to maintain the texture, consistency, and mouthfeel of cheese, particularly in processed cheeses, spreads, and soft varieties of cheese. Starch, carrageenan, and guar gum are some common stabilizers are used in cheese. Starch is a polysaccharide which consists of a large number of glucose units and bonded together with the help of glycosidic bonds. Starch is basically composed of amylase and amylopectin, and these two polymers are linked into semi-crystalline granules which are highly hydrophilic and characterized by swelling properties (Agoda-Tandjawa *et al.*, 2017).

Modified starch is added to shredded cheese to prevent clumping, ensuring that the cheese remains free-flowing and easy to sprinkle. In processed cheese spreads, starch enhances creaminess and also helps to maintain texture. Carrageenan is widely used as a thickener and gelling agent in food. In cheese, it helps retain the moisture and giving a smooth and creamy texture to spreads and soft cheeses. Carrageenan also provides structure and making processed cheese slices more durable and easier to handle. Guar Gum improves the consistency and stability of cheese, especially in low-fat varieties where achieving a creamy texture can be challenging. Guar gum also helps stabilize the moisture and preventing separation in cheese spreads.

- v. **Starter Culture:** These are lactic acid bacteria that convert lactose to lactic acid. It is essential for cheese formation.

vi. **Rennet:** Rennet is an enzyme that coagulates milk, which is a crucial step in separating curds from whey. It is a complex set of enzymes produced in the stomachs of ruminant mammals. Chymosin is the key component of rennet. It is a protease enzyme that curdles the casein in milk. In addition to chymosin, rennet also contains other enzymes, such as pepsin and a lipase

Flavor and appearance:

i. **Colorant:** Mainly annatto and carmine are used as a colourant for manufacturing of cheese. Addition of food colorant to give cheese a more appealing and consistent appearance. Annatto colour is a pigment extracted from “the pericarp of the seed of *Bixa Orellana*.” It is a water-soluble compound that is yellow-orange color. Diapocarotenoids are the main color components in annatto. The methyl ester of a dibasic fatty acid forms the bixin pigment, which leads to the formation of hydrolyzed water-soluble norbixin on treatment with alkalis. Annatto is available in two types like bixin (oil extract) and norbixin (powdered form). Food colour is generally used to provide good quality, satisfy consumers, or assist marketing (Peira *et al.*, 2018; Teigiserova *et al.*, 2020).

ii. **Flavouring:** Different types of flavouring such as spices, herbs, and smoke are added to enhance the flavor of the cheese. Flavor Enhancers is one of the most critical aspects of cheese, and certain additives help to enhance it. Enzymes, starter cultures, and lipases are directly impact cheese flavor.

iii. **Enzymes:** Enzymes plays important roles in cheese. Mixtures of enzymes are accelerate the ripening process for aged of cheeses. Lipase enzymes break down fats and enhancing flavors in certain types of cheese. Lipases contribute to a stronger, more pungent taste in parmesan and feta cheese. Lipase is a popular additive for cheeses that need a richer and more intense flavor profile. Flavor enhancers are natural components of cheese-making, they are adjusted to produce consistent taste across the batches. It plays an important factor for commercial cheese making for maintains quality.

Preservation and safety:

i. **Antioxidant:** It prevents oxidation of cheese and prevent to spoilage of cheese. BHA and BHT antioxidants are added in cheese.

ii. **Preservation:** Preservation inhibit the growth of harmful bacteria and mold. It extending the shelf life of the cheese. There are two primary preservatives used in cheese are Natamycin

(E235) and Sorbic Acid Salts (E200, E202, E203). Natamycin (E235) is also known as pimaricin. It is a natural antifungal agent commonly used to prevent mold on hard and semi-hard cheeses. It is usually applied as a surface treatment, either by dipping or spraying the cheese. Natamycin inhibits mold growth on the cheese rind, which is especially beneficial for cheeses that require aging. Sorbic acid and its salts, including potassium and calcium sorbate, are used as preservatives that inhibit yeast and mold growth.

These salts are applied to the surface of soft cheeses and spread to prevent spoilage, particularly in cheeses with a high moisture content. Sorbic acid salts dissolve in acidic environments. Sorbic acid is suitable for soft cheeses and they prevent spoilage without affecting taste or texture. Both Natamycin and sorbic acid salts provide an added layer of protection against spoilage, allowing cheeses to be stored safely in longer periods and in a wider range of conditions. Chemical preservatives are extensively used to manufacture and market food items in recent times (Davidson and Brannen 2005).

iii. **Salts:** It helps to control microbial growth and also restore calcium balance.

Nutritional enhancement:

Vitamins and minerals are added in cheese to increase the nutritional value of the cheese.

Conclusion

Additives in cheese play an important role in enhancing its texture, flavor, appearance, and shelf life. Additives ensure that cheese products are safe, consistent, and high-quality, it is also suitable for widespread distribution and storage. Cheese additives like natamycin and sorbic acid salts help to prevent spoilage, carrageenan and guar gum stabilizers improve texture of processed cheese varieties. Flavor enhancers and colorants also contribute to the appeal and enjoyment of cheese. Citric acid is used as acidifiers. It lowers the pH of milk and helps the proteins coagulate and also form curds. Acidifiers are essential for manufacturing of cheeses like ricotta and mozzarella.

References

- Agoda-Tandjawa G, Le Garnec C, Boulenguer P, Gilles M, Langendorff V. Rheological behavior of starch/carrageenan/milk proteins mixed systems: role of each biopolymer type and chemical characteristics. *Food Hydrocoll.* 2017;73:300–312.
- Amin L, Azad M, Samian A. Factor influencing risk perception of food additives. *J Food Agric Environ.* 2013; 11:66–72.

- Cai W, Liu J. The improvement of the risk communication mechanism in food additives under the perspective of consumers' right to know. *J Food Saf.* 2014; 5:167–172
- Davidson PM, Branen AL. Food antimicrobial an introduction. *Food Sci Technol.* 2005; <https://doi.org/10.1201/9781420028737.ch1>
- Peira G, Bollani L, Giachino C, Bonadonna A. The management of unsold food in outdoor market areas: food operators' behaviour and attitudes. *Sustainability.* 2028; 10(4):1180.
- Scott R. *Cheese Making Practice.* Applied Science Pub., London. 1981.
- Teigiserova DA, Hamelin L, Thomsen M. Towards transparent valorization of food surplus, waste and loss: clarifying definitions, food waste hierarchy, and role in the circular economy. *SciTotal Environ.* 2020; 706:136033
- Wang C, Wu J, Gao X. Basic attributives, functions and characteristics of food additives. *China Food Additives.* 2015; 10:154–158
- WHO. The World Health Organization (WHO) and UNICEF jointly convened the International Conference on Primary Health Care in Alma-Ata, USSR. 1978.
- Wu L, Zhang Q, Shan L, Chen Z. Identifying critical factors influencing the use of additives by food: enterprises in China. *Food Control.* 2013a; 31:425–432.



Volume: 05 Issue No: 12

EVOLUTION OF AGRICULTURE IN INDIA: FROM TRADITIONAL PRACTICES TO SUSTAINABLE FUTURES

Article ID: AG-VO5-I12-38**Dr. Kamesh T. M***

Assistant Professor (Agricultural Economics), School of Agricultural Sciences,
Dhanalakshmi Srinivasan University, Trichy, Tamil Nadu, India

*Corresponding Author Email ID: kameshnkl@gmail.com

Abstract

This paper explores the evolution of Indian agriculture from the era of traditional practices (Agriculture 1.0) to the modern, sustainability-driven framework (Agriculture 5.0). The transition encompasses phases of transformation such as the Green Revolution, precision and digital agriculture, and the emerging paradigm of regenerative and climate-smart farming. Each stage is marked by significant technological, socio-economic, and environmental shifts that continue to redefine the agricultural landscape of India.

Keywords: Green Revolution, Precision Agriculture, Digital Agriculture, Sustainability, Regenerative Farming.

1. Introduction

Agriculture has long served as the cornerstone of India's economy, culture, and livelihood. It supports nearly half of the population and contributes substantially to the nation's GDP..



Over the decades, Indian agriculture has evolved through major transitions—shifting from traditional subsistence farming systems to modern, technology-enabled, and sustainability-oriented frameworks. Each stage of this evolution reflects the dynamic interplay of technological innovation, policy reforms, and socio-economic change. Today, agriculture in India stands at the threshold of a new era—one that combines productivity with sustainability, aiming to ensure food security while conserving natural resources for future generations.

2. Methodology

This study employs a historical and analytical approach to trace the progressive transformation of Indian agriculture through five distinct phases—Agriculture 1.0 to Agriculture 5.0. Each phase is characterized by specific technological advancements, production systems, and sustainability challenges. The analysis draws upon secondary data from government reports, academic publications, and international organizations such as the Food and Agriculture Organization (FAO) and the World Bank. The objective is to provide an integrated understanding of how technological and institutional shifts have shaped the trajectory of Indian agriculture.

3. Agriculture 1.0 – Traditional Agriculture

The period before the 1960s represents India's traditional agricultural system, which was largely subsistence-oriented, labor-intensive, and dependent on natural resources. Farming was primarily carried out to meet household needs, with minimal market orientation. In this era, farmers relied on simple tools and implements such as wooden ploughs, sickles, and bullock-driven carts for field operations. Irrigation facilities were scarce, and cultivation was heavily dependent on monsoon rains and natural water bodies. Multi-cropping, crop rotation, and intercropping were commonly practiced to maintain soil fertility and reduce the risk of crop failure. However, this system faced several challenges. Productivity remained low due to limited mechanization, poor access to quality inputs, and the absence of scientific farming methods. Crop failures were frequent, mainly caused by droughts, floods, and pest infestations. The high dependence on human and animal labor further constrained efficiency and limited the expansion of cultivated land.

4. Agriculture 2.0 – The Green Revolution

The Green Revolution, initiated in the 1960s, marked a turning point in Indian agriculture. Through the introduction of high-yielding variety (HYV) seeds, chemical fertilizers,

and irrigation infrastructure, agricultural productivity increased dramatically, especially in regions such as Punjab, Haryana, and Uttar Pradesh. The major innovations of this period included the introduction of HYV seeds like IR-8 rice and Lerma Rojo wheat, which significantly improved yields. The use of chemical fertilizers and pesticides enhanced soil fertility and pest resistance, while the mechanization of agriculture — through tractors, harvesters, and pump sets — reduced manual drudgery.

Large-scale irrigation projects, including dam and canal construction, ensured water availability throughout the year. The impact of the Green Revolution was profound. Food grain production rose substantially, transforming India from a food-deficit nation into one that was self-sufficient. It also reduced famine occurrences and created rural employment opportunities. However, the revolution had some drawbacks, including soil degradation, water table depletion, and regional inequalities due to uneven adoption of technology.

5. Agriculture 3.0 – Precision Agriculture

Emerging in the 1990s and early 2000s, precision agriculture represented a data-driven and technology-oriented phase in Indian farming. It aimed to optimize the use of inputs and resources through scientific monitoring and analysis, thereby improving productivity and sustainability. Key technologies such as GPS and GIS mapping were employed for soil health monitoring, land-use planning, and crop management. Sensors helped measure moisture, temperature, and nutrient levels, allowing for site-specific crop management. Data analytics tools guided irrigation scheduling, fertilizer dosage, and pest control decisions, resulting in efficient farming practices. The adoption of precision agriculture led to increased resource efficiency and input optimization. It improved yield predictability, reduced wastage, and minimized environmental impact. Moreover, this phase encouraged the use of e-agriculture platforms, helping farmers access real-time market information and digital advisory services.

6. Agriculture 4.0 – Digital Agriculture

The advent of Artificial Intelligence (AI), the Internet of Things (IoT), and Big Data has ushered in the era of Digital Agriculture. This phase focuses on creating a connected ecosystem where farmers, machines, and markets interact seamlessly through digital technologies. IoT-based sensors are now used to monitor soil health, temperature, and pest activity in real time, helping farmers make quick and informed decisions. Drones are employed for aerial spraying, mapping, and crop health imaging, reducing labor requirements and increasing accuracy.

Artificial intelligence and machine learning tools enable predictive analytics for crop planning, weather forecasting, and early pest detection. Additionally, mobile apps and e-marketing platforms empower farmers by providing instant access to market prices, weather updates, and expert advice. Digital agriculture has transformed farm management by enabling real-time monitoring, improving decision-making, and reducing production costs through automation. It enhances resilience against climate variability and ensures better integration of farmers into supply chains and financial services.

7. Agriculture 5.0 – Sustainable and Regenerative Agriculture

Agriculture 5.0 represents the next frontier in agricultural evolution, where technology and sustainability converge to build climate-resilient, carbon-neutral, and regenerative farming systems. The focus of this phase is on **producing more** with fewer resources while restoring ecological balance. Regenerative farming practices such as minimal tillage, cover cropping, and crop-livestock integration are encouraged to enhance soil health and biodiversity. Organic and natural farming methods are promoted to reduce chemical dependency, while Climate-Smart Agriculture (CSA) emphasizes carbon sequestration, water-use efficiency, and renewable energy adoption. The concept of a circular economy in agriculture supports the reuse and recycling of crop residues, thereby minimizing waste and enhancing sustainability. Looking ahead, the integration of AI, robotics, and renewable energy systems will redefine sustainable farming practices. Government support through green finance, carbon credit systems, and favorable policies will be essential to encourage widespread adoption. Education, capacity building, and awareness programs will further ensure that farmers actively participate in the transition toward sustainable and climate-resilient agriculture.

8. Conclusion

The evolution of Indian agriculture from manual, subsistence-based systems to digitally enabled, sustainable frameworks showcases the sector's resilience and capacity for transformation. Each phase—whether the Green Revolution or the digital transition—has contributed to improving productivity and food security. However, the challenge now lies in reconciling technological advancement with environmental sustainability and social equity. The vision of Agriculture 5.0 offers a pathway toward a climate-resilient and sustainable agricultural future—one that balances innovation, inclusivity, and ecological stewardship for generations to come.

References

1. Sharma, R., Aravind, T., & Sharma, R. (2019). Sustainable agriculture: Trends and opportunities for the 21st Century. *Journal of Applied and Natural Science*, 11(3), 666–672.
2. Singh, D. (1999). The green revolution and the evolution of agricultural education and research in India. *Genome*, 42(4), 557–561.
3. FAO (2021). *The State of Food and Agriculture 2021: Making Agrifood Systems More Resilient*. Food and Agriculture Organization of the United Nations, Rome.
4. Government of India (2023). *Agriculture and Farmers Welfare Annual Report*, Ministry of Agriculture and Farmers Welfare, New Delhi.



Volume: 05 Issue No: 12

INNOVATION IN FARM TRACTORS: DRIVING THE FUTURE OF SUSTAINABLE AGRICULTURE

Article ID: AG-VO5-I12-39***Nisha.S¹ and Dharshini Priya.M²**

Department of Agricultural Engineering, Nandha Engineering College, Perundurai,
Tamil Nadu

*Corresponding Author Email ID: nishasenthilkumar07027@gmail.com

Abstract

Modern farm tractors have changed from simple machines into smart, connected systems that help farmers work faster and more accurately. New features such as GPS auto-steering, smart sensors, automation, and electric or hybrid engines reduce labour, save fuel, and cut pollution. With IoT, AI, and data analytics, tractors now guide real-time decisions about field operations and input use, supporting climate-smart, sustainable farming and better food production.

Key words: Farm tractors Tractor, innovation Sma1, tractors, Smart sensors and automation, Climate-smart farming

Introduction

Modern farm tractors are becoming the backbone of sustainable agriculture by combining mechanical power with digital intelligence. Their advanced features—GPS guidance, smart sensors, variable-rate application, and cleaner or hybrid engines—help farmers increase productivity while reducing labour, fuel use, and emissions. Overall, these innovations support climate-smart, resource-efficient farming and show that future investment in smart tractor technology is essential for food security, farmer income, and environmental protection.

Study details

1. Evolution of modern farm tractors

Early tractors were simple, fuel-hungry machines that only pulled implements. Today they are efficient, comfortable, and computer-controlled, helping farmers do more work with less time and fuel.



2. GPS guidance and auto-steering



GPS systems guide the tractor in straight, accurate lines so there is very little overlap or missed area. Auto- steering reduces operator fatigue and saves fuel, seed, and chemicals.

3. Smart sensors and monitoring

Sensors on the tractor and implements measure soil moisture, crop height, machine load, and fuel use.



This real-time information helps the farmer adjust speed, depth, and inputs immediately.

4. Variable-rate input application

Digital maps and controllers, the tractor can change seed, fertilizer, or pesticide rate automatically across the field. Poor areas get more help, good areas get less, reducing waste and cost.

5. Electric and hybrid tractor engines

Electric and hybrid tractors use batteries and electric motors, sometimes combined with a small engine. They are quieter, use less diesel, and produce fewer emissions than traditional tractors.

6. IoT and telematics in tractors

Tractors are connected to the internet, sending data to a mobile or computer dashboard. Owners can track location, fuel level, working hours, and faults from anywhere.

7. AI-based tractor control and analytics

Artificial intelligence studies past data from the tractor and field to suggest best speed, route, and settings. It can also predict breakdowns early, reducing downtime and repair cost.

8. Productivity and fuel-saving impacts

Modern technologies allow more land to be covered in less time, with fewer workers. Accurate operations and better engine control cut fuel consumption per hectare.

9. Environmental benefits and low emissions

By saving fuel and using inputs more carefully, innovative tractors reduce greenhouse gas emissions and chemical runoff. This supports climate-smart and environmentally friendly farming.

10. Adoption issues for small farmers

High purchase cost, lack of training, and weak service support make new tractors hard to adopt for small and marginal farmers. Credit schemes, rental services, and training can help close this gap.

Conclusion

Modern farm tractors now combine strong engines with smart technologies like GPS, sensors, and automation. These innovations help farmers save fuel and labour, work more accurately, and reduce pollution. Overall, advanced tractors are key tools for future sustainable, climate-friendly agriculture



Reference

Lopez, Maria, and Rossi, Giovanni. "Integration of Smart Sensors and Internet of Things (IoT) in Precision Agriculture." *Frontiers in Plant Science*, 2025.



Volume: 05 Issue No: 12

LOW CARBON AQUAFEEDS: EMERGING INGREDIENTS AND CARBON-FOOTPRINT REDUCTION STRATEGIES

Article ID: AG-VO5-I12-40**Chinmayee Puja Rani Sethi***

M.F.Sc, Fish Nutrition and Feed technology department, ICAR-CIFE , Mumbai

Versova, Andheri West-400061

*Corresponding Author Email ID: chinmayeepujarani@gmail.com

Abstract

Aquaculture is central to global food security, yet its environmental impact is increasingly scrutinized as the sector expands. Feed production—especially ingredients such as fishmeal, fish oil, and land-intensive crop proteins—accounts for the majority of aquaculture’s greenhouse-gas (GHG) emissions. Developing low-carbon aquafeeds is therefore critical for aligning industry growth with climate-neutrality goals. This review synthesizes emerging evidence on alternative ingredients and carbon-reduction strategies capable of lowering the feed footprint without compromising fish performance. Novel protein sources including insect meals, microbial single-cell proteins, microalgal biomass, and upcycled agro-industrial by-products demonstrate considerable potential for reducing CO₂-equivalent emissions when produced through circular systems or powered by renewable energy. Complementary interventions—such as precision formulation, amino-acid balancing, energy-efficient feed processing, and optimized feed-conversion ratios (FCR)—further enhance emission savings across the feed life cycle. Although technological, economic, and regulatory barriers remain, life-cycle assessment (LCA) studies consistently indicate that integrating low-impact ingredients with improved feed management can substantially reduce aquaculture’s overall carbon intensity. Advancing low-carbon aquafeeds is therefore a cornerstone strategy for climate-smart aquaculture, enabling sustainable intensification while safeguarding environmental integrity.

Introduction

why low-carbon feeds matter?

Aquaculture provides an increasing share of global animal protein, but its environmental sustainability depends heavily on feed. Feed production commonly dominates farm-level impacts for many species; the carbon footprint of aquafeeds arises from raw material production (harvested forage fish, soybean cultivation, etc.), ingredient processing, transport, and feed use efficiency (feed conversion ratio, or FCR). Reducing emissions from feed is therefore the most direct lever to shrink aquaculture's climate impact while maintaining production. Traditionally, aquafeeds have relied heavily on fishmeal and fish oil derived from wild forage fisheries. While these marine ingredients offer excellent nutritional quality, concerns have grown regarding their environmental costs—ranging from overexploitation of pelagic fish stocks to high CO₂ emissions associated with harvesting and processing. At the same time, improvements in feed formulation, precision feeding, extrusion technology, and supply chain logistics offer additional pathways to drive down carbon emissions. A holistic approach that combines low-impact ingredients with optimized processing and improved feed conversion ratio (FCR) can potentially reduce the carbon footprint of aquaculture by 30–60% for many species, according to recent modelling studies (FAO, 2022).

Low carbon aquafeeds

Low-carbon aquafeeds refer to fish feeds that are intentionally designed, formulated, and processed to produce significantly lower greenhouse-gas (GHG) emissions across their entire life cycle—beginning from raw-material production to feed manufacturing, transportation, and farm-level use. They represent a major transition in aquaculture nutrition, driven by the need to reduce the industry's environmental footprint while still supporting rapid growth in global seafood demand. Traditional feeds rely heavily on ingredients such as fishmeal, fish oil, soy, and other crop-based proteins, all of which have substantial carbon impacts because they require intensive land use, energy inputs, and in some cases, direct extraction from marine ecosystems. In contrast, low-carbon aquafeeds rely on novel, circular, and sustainably sourced ingredients combined with energy-efficient processing and precision formulation to reduce emissions without compromising fish health or growth.

A key feature of low-carbon aquafeeds is the use of alternative protein sources that produce fewer emissions compared to conventional ingredients. Examples include insect meals, single-cell proteins, microalgae, and fermented or upcycled agricultural by-products.

Key emerging low-carbon ingredient classes

Insect Meal

Insect meal, especially from black soldier fly larvae (BSFL), mealworms, and crickets, has emerged as one of the most climate-friendly protein sources for aquafeeds. Insects can grow rapidly on organic waste streams such as fruit peels, poultry litter, brewery residue, kitchen waste, and agro-industrial by-products. This allows insect farming to function within a circular economy where nutrients are continuously recycled instead of being lost as waste. The carbon footprint of insect meal is considerably lower than soybean meal or fishmeal because insects require very little land, water, and feed to produce high-quality protein. Their biological conversion efficiency is extremely high, meaning they produce more edible protein per kilogram of feed compared to animals or plants. In addition, insect production avoids land-use change, a major source of global CO₂ emissions, because no forests need to be cleared for cultivation. Nutritionally, insect meal contains 40–60% protein, rich lipid content, and essential amino acids comparable to fishmeal. It also provides lauric acid, chitin, and antimicrobial peptides that can improve fish gut health and immunity. Since insect production can be conducted near aquafeed mills, transportation emissions are also minimized. These combined advantages make insect meal a strong candidate for future low-carbon feed formulations.

Single-Cell Proteins (Bacteria, Yeast, Fungi)

Single-cell proteins (SCPs) are produced by cultivating microorganisms—such as bacteria, yeasts, or filamentous fungi—in controlled fermentation systems. SCPs offer a revolutionary solution to reducing the carbon footprint of aquafeeds because they do not depend on agricultural land, favorable climate, or irrigation. Instead, they grow in compact bioreactors using industrial side streams like methane, methanol, molasses, or even captured carbon dioxide as substrates. This ability to convert waste gases or agricultural residues into high-quality protein drastically lowers emissions associated with producing protein-rich ingredients. SCPs typically contain 50–75% crude protein, with excellent amino acid profiles suitable for carnivorous and omnivorous fish species. They also supply nucleotides, vitamins, and cell-wall components that support immunity and gut function. Since production takes place in closed systems, SCP quality

is consistent throughout the year and not affected by climate variability. Moreover, when powered by renewable energy sources, SCP fermentation becomes one of the lowest-carbon protein production technologies available. These features position SCPs as a major long-term ingredient for carbon-neutral aquafeeds.

Microalgae and Algal Oils

Microalgae are another highly promising low-carbon ingredient due to their exceptional nutritional properties and natural ability to capture CO₂. Many microalgal species are rich in omega-3 fatty acids (EPA and DHA), which are essential for fish health and typically derived from wild-caught fish oil. By replacing fish oil with algal oil, aquaculture can significantly reduce pressure on marine forage fisheries. Microalgae can be cultivated in seawater, brackish water, or even wastewater, meaning that their production does not compete with human food crops or freshwater resources. Some algal farms operate in photobioreactors that capture CO₂ from industrial sources and convert it into biomass through photosynthesis, thereby serving as carbon sinks rather than carbon sources. Although the drying process can be energy-intensive, innovations in solar drying, low-energy harvesting, and integrated biorefineries are steadily lowering energy consumption and emissions. Microalgae also provide pigments, antioxidants, vitamins, and immunostimulants that enhance fish health. Because of their high lipid quality and digestibility, microalgae are increasingly used in high-value aquaculture, especially salmon and trout diets. As technology improves, microalgal ingredients have the potential to become a cornerstone of sustainable, low-carbon feed systems.

Upcycled Agro-Industrial By-Products

A large proportion of low-carbon aquafeeds depend on the efficient use of upcycled ingredients derived from existing food and processing industries. These include oilseed cakes, rice bran, brewery waste, fruit pulp residues, fish-processing trimmings, blood meal, feather meal, and other nutrient-rich by-products. The unique advantage of these ingredients is that they do not require new land, energy, or fresh resources to produce. Because they are obtained from materials that already exist as co-products, their life-cycle emissions are substantially lower than primary ingredients like fishmeal or soybean meal. Modern processing technologies—such as enzymatic hydrolysis, fermentation, and extrusion—can significantly improve their digestibility, protein content, and nutrient availability, making them well-suited for fish and shrimp diets. Upcycling also reduces waste disposal emissions, especially methane generation from

decomposing organic matter in landfills. When locally sourced, these by-products also reduce transportation-related emissions, making them a practical and climate-friendly option for regional aquaculture industries. Their affordability further increases their attractiveness for farmers in developing countries.

Strategies to reduce carbon footprint print

1. Using Low-Carbon Alternative Ingredients

- Replace fishmeal/fish oil with low-impact alternatives
- Use insects, single-cell proteins (SCP), microalgae
- Prefer ingredients produced using renewable energy or waste substrates

Choosing ingredients with a lower life-cycle greenhouse-gas intensity is the most direct strategy to reduce feed-related emissions. Novel ingredients such as insect meal, microbial single-cell proteins, and microalgae have significantly lower CO₂ emissions per kilogram of protein when produced using renewable energy or organic waste streams (Smetana et al., 2023). These ingredients avoid the land-use change associated with soy and reduce fishing pressure on marine resources used for fishmeal and fish oil (Naylor et al., 2021). LCAs show that insect meals grown on agro-industrial residues and bacterial SCP produced via natural-gas or hydrogen fermentation often outperform traditional ingredients in carbon efficiency (Cumberlege et al., 2016). Therefore, shifting ingredient portfolios towards low-carbon proteins is a foundational approach in sustainable aquafeed development.

2. Optimizing Nutrient Formulation and Amino Acid Balancing

- Reduce crude protein levels while maintaining essential amino acids
- Use digestibility-based formulations
- Improve nutrient utilization to reduce nitrogen waste

Feed formulation optimization—especially adjusting the protein-to-energy ratio—can reduce the embedded carbon footprint of aquafeeds. Over-formulating protein increases the use of high-emission ingredients and leads to unnecessary nitrogen excretion by fish. By balancing essential amino acids using digestible nutrient values, feed manufacturers can reduce crude protein levels without compromising growth, which lowers upstream ingredient-related emissions (Sarker et al., 2016). The adoption of crystalline amino acids and highly digestible alternative proteins has shown measurable reductions in feed conversion ratios (FCR), meaning less feed (and embedded

CO₂) is required to produce one unit of fish biomass (Bachinger et al., 2022). Thus, nutrient-efficient formulation significantly reduces both feed production and on-farm emissions.

3. Improving Feed Conversion Ratio (FCR) and Precision Feeding

- Reduce feed wastage through automated feeders
- Use sensors and real-time monitoring
- Match feed supply to fish appetite and environmental conditions

Improving FCR—the amount of feed needed to produce one kilogram of fish—is one of the most impactful ways to lower the carbon footprint of aquaculture. Precision feeding systems that use sensors, artificial intelligence, and automated feeders can reduce waste by delivering feed only when fish are actively feeding (Thornburg et al., 2025). Better feeding accuracy ensures that a larger portion of the feed's embedded carbon is converted into fish biomass rather than being lost as uneaten feed or metabolic waste. Studies show that precision feeding can reduce feed usage by 10–20%, which proportionally reduces the overall GHG emissions associated with aquafeed (FAO, 2022). Thus, optimized feeding practices increase efficiency while reducing environmental impact.

4. Energy-Efficient Feed Processing and Use of Renewable Energy

- Optimize extrusion, drying, grinding and pelleting
- Recover waste heat
- Power feed mills with solar, wind or hydro energy

Feed manufacturing is energy-intensive, especially during extrusion and drying, making it a major hotspot in feed-related emissions. Implementing process improvements—such as optimized barrel temperatures, lower specific mechanical energy (SME), and advanced drying technologies—can significantly reduce energy use (Pennells et al., 2025). Integrating waste-heat recovery systems and shifting to renewable energy sources can further lower CO₂ emissions from manufacturing. Studies show that electrification of feed mills combined with solar or biomass energy can cut production emissions by more than 30% (Pelletier & Tyedmers, 2010). Therefore, cleaner and more efficient processing directly contributes to a lower carbon footprint per tonne of feed.

5. Localized Sourcing and Efficient Transportation

- Reduce transport distances

- Develop regional ingredient hubs
- Improve logistics and shipping efficiency

Transportation contributes a smaller but still relevant portion of aquafeed emissions, particularly for bulky ingredients transported across continents. Localizing ingredient production (e.g., regional insect or microalgae farms) and improving logistics efficiency can reduce emissions associated with long-distance freight (Toledo et al., 2021). However, LCAs show that localization must be evaluated carefully because ingredients produced locally using fossil energy may generate higher emissions than imported materials produced with cleaner energy (Vatsanidou et al., 2025). Optimized supply-chain logistics, improved load management, and reduced empty return trips collectively help lower the carbon burden of ingredient transport.

6. Adopting Circular Economy Approaches

- Use agricultural and food-industry by-products
- Support upcycling of waste streams
- Co-locate feed companies with industries producing residues

Circular economy strategies are highly effective in reducing aquafeed carbon footprints because they utilize materials that already exist rather than producing new resources. Upcycled ingredients—such as oilseed press cakes, brewery spent grain, fruit waste, and other food-industry by-products—come with low or even negative assigned emissions when LCAs credit avoided waste disposal (Alloul et al., 2018). Co-locating SCP or insect production facilities next to food-processing plants further reduces transport-related emissions and creates industrial symbiosis (Smetana et al., 2023). These approaches decrease pressure on land and energy while converting waste into high-value feed components, making them central to low-carbon feed strategies.

7. Strengthening Life-Cycle Assessment (LCA) and Carbon Accounting

- Conduct ingredient and feed LCA
- Identify hotspots and improvement opportunities
- Standardize reporting across feed manufacturers

Robust carbon footprint reduction requires transparent measurement through life-cycle assessment. LCAs help feed manufacturers identify hotspots—such as energy use, ingredient sourcing, or transportation—and determine where improvements generate the highest emissions

savings (FAO, 2020). Standardized LCA frameworks ensure that different ingredients and processes can be compared accurately, promoting evidence-based decision-making across the value chain (Pelletier & Tyedmers, 2010). Transparent carbon accounting also supports certifications and eco-labels that reward low-carbon feed producers, enabling market incentives to accelerate sustainability transitions.

Conclusion

Low-carbon aquafeeds represent a critical pathway for transforming aquaculture into a climate-smart food-production system. As the industry continues to expand globally, traditional reliance on fishmeal, fish oil, and land-intensive plant proteins is no longer environmentally sustainable. The emergence of novel ingredients—such as insect meals, single-cell proteins, microalgae, and upcycled agro-industrial by-products—offers viable, low-emission alternatives that significantly reduce the feed sector's dependence on high-impact raw materials. When combined with carbon-reduction strategies such as precision nutrition, improved feed-conversion efficiency, renewable-energy-based feed manufacturing, and circular production models, these innovations can substantially lower greenhouse-gas emissions across the aquafeed life cycle. Although economic, technological, and regulatory barriers still limit widespread adoption, current evidence clearly shows that integrating sustainable ingredients with efficient production practices can meaningfully reduce aquaculture's carbon footprint without compromising fish growth or health. Therefore, advancing low-carbon aquafeeds is not only feasible but essential for ensuring the long-term sustainability, resilience, and climate compatibility of the global aquaculture sector.

References

- Aldridge, S., & Ding, Y. (2023). Single-cell protein as a sustainable ingredient for aquafeeds: Production, nutritional value and environmental impact. *Aquaculture Reports*, 30, 101576.
- Alloul, A., Ganigué, R., Spiller, M., & Vlaeminck, S. E. (2018). Protein production by biomass from wastewater: A review. *Critical Reviews in Environmental Science and Technology*, 48(14), 1391–1425.
- Bachinger, F., Schmidt, J., Sanders, J., & Troffaes, M. M. (2022). Carbon footprint of plant-based proteins used in aquafeeds: A life-cycle perspective. *Journal of Cleaner Production*, 372, 133871.

- Barroso, F. G., de Haro, C., Sánchez-Muros, M. J., Venegas, E., Martínez-Sánchez, A., & Pérez-Bañón, C. (2014). The potential of insect meal as a sustainable ingredient for aquafeeds. *Animal Feed Science and Technology*, 197, 1–12.
- Béné, C., Barange, M., Subasinghe, R., Pinstup-Andersen, P., Merino, G., Hemre, G. I., & Williams, M. (2016). Feeding 9 billion by 2050—Putting fish back on the menu. *Food Security*, 7, 261–274.
- Cumberlege, T., et al. (2016). Assessment of environmental footprint of FeedKind protein. Carbon Trust.
- Food and Agriculture Organization. (2020). The state of world fisheries and aquaculture 2020: Sustainability in action. FAO.
- Food and Agriculture Organization. (2022). The state of world fisheries and aquaculture 2022: Towards blue transformation. FAO.
- Gasco, L., Finke, M., & van Huis, A. (2020). Can diets containing insects promote animal health? *Journal of Insects as Food and Feed*, 6(4), 333–338.
- Haupt, A., Fawole, F. J., & He, S. (2021). Microalgae as sustainable aquafeed ingredients: Nutritional composition, digestibility and functional role. *Reviews in Aquaculture*, 13(1), 291–318.
- Henry, M., Gasco, L., Piccolo, G., & Fountoulaki, E. (2015). Review on the use of insects in aquafeeds. *Animal Feed Science and Technology*, 203, 1–22.
- Klinger, D., & Naylor, R. (2012). Searching for solutions in aquaculture: Charting a sustainable course. *Annual Review of Environment and Resources*, 37, 247–276.
- Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., Tran, N., ... Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature*, 591, 551–563.
- O'Connell, T. S., Garcia, A. L., & Soler-Vila, A. (2020). Microalgae in aquafeed development: A review of nutritional benefits and environmental advantages. *Algal Research*, 50, 102002.
- Palstra, A., Planas, M., & Zambonino-Infante, J. (2019). Sustainability and performance of microbial proteins in aquafeeds. *Aquaculture Nutrition*, 25(6), 1511–1524.

- Pelletier, N., & Tyedmers, P. (2010). Life-cycle assessment of aquaculture systems. *Environmental Science & Technology*, 41, 105–111.
- Ritala, A., Häkkinen, S. T., Toivari, M., & Ojala, L. (2017). Single-cell protein—State-of-the-art, industrial landscape and patents. *Frontiers in Microbiology*, 8, 2009.
- Sarker, P. K., Kapuscinski, A. R., Lanois, A. J., Livesey, E. D., Piggott, N., & Coley, M. (2016). Towards sustainable aquafeeds: Evaluating the environmental footprint of novel feed ingredients. *Journal of Industrial Ecology*, 20(6), 1366–1377.
- Smetana, S., et al. (2023). Environmental impact potential of insect production chains: A comprehensive assessment. *Scientific Reports*.
- Tacon, A. G. J., & Metian, M. (2015). Feed matters: Satisfying the feed demand of aquaculture. *Reviews in Fisheries Science & Aquaculture*, 23(1), 1–10.
- Thornburg, J., et al. (2025). Feed the fish: A review of aquaculture feeders and their strategic implementation. *Journal of Aquaculture Technology*.
- Toledo, J., Veiga, M., & Coelho, D. (2021). Circular economy approaches in aquaculture feed production. *Sustainability*, 13(22), 12560.
- Van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual Review of Entomology*, 58, 563–583.
- Vatsanidou, A., et al. (2025). Comparative life cycle assessment of animal feed and aquafeed formulations. *Agriculture*.
- Wei, X., Zhang, Q., & Liu, H. (2022). Life-cycle assessment of insect-based and microalgae-based feed ingredients. *Journal of Cleaner Production*, 350, 131489.

CLIMATE CHANGE AFFECTING PHENOLOGICAL CHANGES IN TREES IN HIMALAYAN REGION OF INDIA

Article ID: AG-VO5-I12-41

Tara Thakur¹ and Parminder Kaur Baweja²

1. Research Scholar, Department of Environmental Science, Dr. Y S Parmar University Of
Horticulture and Forestry, Nauni-Solan-173230 (HP), India

2. Principal Scientist, Department of Environmental Science, Dr. Y S Parmar University Of
Horticulture and Forestry, Nauni-Solan-173230 (HP), India

*Corresponding Author Email ID: tarathakur02@gmail.com

Abstract

Climate change has emerged as one of the most critical drivers of ecological transformations worldwide, and its effects are particularly pronounced in fragile mountain ecosystems. The Indian Himalayan Region (IHR), often referred to as the “water tower of Asia” and a global biodiversity hotspot, is highly sensitive to variations in temperature and precipitation. Among the many ecological processes impacted, **phenology—the seasonal timing of biological events such as leafing, flowering, fruiting and senescence—stands out as one of the most responsive indicators of climate variability**. In recent decades, Himalayan tree species have exhibited noticeable shifts in their phenophases, reflecting the strong influence of rising mean air temperatures, erratic rainfall patterns, and altered snowmelt dynamics. Species such as *Pinus roxburghii*, *Quercus leucotrichophora*, *Rhododendron arboreum*, *Myrica esculenta* and several multipurpose trees (*Abies pindrow*, *Bauhinia variegata*, *Sapindus mukorossi*) demonstrate advanced or delayed leaf flushing, altered flowering times, and changes in fruit maturation. These shifts not only influence species reproduction and survival but also disrupt pollination, seed dispersal and interdependent ecological relationships. The phenological responses of trees in the Himalayas have cascading consequences for forest regeneration, biodiversity conservation, and the livelihoods of mountain communities dependent on forest resources for food, fodder, fuelwood and medicine. Furthermore, the upward migration of treelines caused by warming threatens alpine meadows and traditional grazing systems, signalling long-term ecological

instability. Given the Himalayan region's ecological fragility and socio-economic importance, understanding how climate change alters tree phenology is vital. Such knowledge can provide insights into ecosystem resilience, guide adaptive forest management and inform policy interventions to mitigate climate risks. This article critically examines observed phenological changes in Himalayan tree species, explores their linkages with climatic variables, and highlights broader implications for ecosystems and human well-being.

Keywords- Climate Change, Erratic rainfall pattern, Phenological changes, Biodiversity impact.

Introduction

Mountains make up around 25% of the planet's land area and are essential to biodiversity, ecological processes, and human welfare. They directly impact the livelihoods of about half of the world's population by **providing** ecosystem services and necessary goods to human societies. However, some of the fastest rates of climate change are occurring in mountainous areas, with significant ecological and social repercussions. With ecosystems ranging from alpine meadows above the timberline to tropical dry deciduous forests in the lowlands, the Indian Himalayan Region (IHR) is a widely acknowledged hotspot for biodiversity. This region harbors diverse flora and fauna, including medicinal, aromatic and woody tree species of ecological, cultural and commercial significance. These ecosystems are under extraordinary strain because to rapid climate change, endangering species survival, regeneration and distribution while also having an effect on the social and cultural fabric of Himalayan populations. Phenology, the study of periodic biological occurrences including budburst, blooming, fruiting, and leaf fall, has **undergone** major changes as a result of climate change's severe effects on plant physiology, reproduction and seasonal life-cycle events. A very sensitive ecological indicator, phenology shows how temperature, precipitation, photoperiod and snowmelt affect plant responses. Worldwide, there is rising evidence of phenological pattern changes, including as longer growing seasons, delayed autumn senescence and earlier beginning of spring events. These modifications can influence fruit and seed output, pollination success, species interactions and composition and ultimately ecosystem services and functioning. Aside from natural ecosystems, changed phenology also affects rural livelihoods that rely on trees and agroforestry systems, agriculture, water availability and carbon cycling. The IHR's forest ecosystems' susceptibility to climatic variability is demonstrated by the phenological changes in multipurpose tree species and treeline vegetation. Significant progress in leaf emergence, varying

blooming responses, extended growth periods and an upward movement of treelines across many Himalayan states are all shown by long-term research. Alpine meadows are under danger due to these ecological changes, which also diminish the supply of grazing resources and medicinal plants and jeopardize traditional pastoral and community-based economies. Studying phenological fluctuations in the Indian Himalaya is essential for comprehending biological responses to climate change because of the region's ecological significance and social reliance on forest resources. This information can help protect biodiversity and human well-being by informing conservation, sustainable management, and climate adaption efforts. This article emphasizes ecological and socioeconomic ramifications throughout the Himalaya, examines underlying climate factors, and synthesizes observed and anticipated phenological changes in the area.

Table 1 Climatic Factors Affecting Phenological Changes in Himalayan Trees

Climatic Factor	Phenological Stages	Forest Tree species	Description of climatic factors	References
1.Rising Temperatures	Earlier budburst, leafing, and flowering; some species exhibit delayed bud break.	<i>Abies pindrow</i> , <i>Abies spectabilis</i> , <i>Betula utilis</i> , <i>Bauhinia variegata</i> , <i>Pinus roxburghii</i> , <i>Acacia catechu</i>	Heat units accumulate faster, but inadequate chilling in warmer winters can postpone bud break.	Chauhan <i>et al.</i> , 2025, Kumar <i>et al.</i> ,2024,
2.Snowfall and Snowmelt Shifts	Altered spring development; delayed phenophases in alpine/subalpine species	<i>Rhododendron arboreum</i> , <i>Myrica esculenta</i>	Early snowmelt exposes soil sooner, accelerating growth; late melting delays leaf-out and blooming	Crepaz <i>et al.</i> , 2024, Mishra <i>et al.</i> , 2024
3.Monsoon Variability	Delayed/reduced blooming and fruiting; flower-fruit damage	<i>Bauhinia variegata</i> , <i>Myrica esculenta</i>	Reproductive success is decreased by drought, whereas flowers and fruits	Meghwal <i>et al.</i> , 2018, Chand <i>et al.</i> , 2017

			are harmed by heavy rainfall.	
4.Extreme Weather Events	Reduced seed viability, tissue/fruit damage, and early leaf flushing	<i>Quercus leucotrichophora</i> , <i>Betula utilis</i> , <i>Rhododendron arboreum</i>	Drought decreases fruit set, late frost damages immature tissues, and heatwaves speed up flushing but increase stress.	Augspurger <i>et al.</i> , 2011, Chand <i>et al.</i> , 2017, Singh <i>et al.</i> , 2023
5.Seasonal Warming Trends	Altered dormancy and chilling requirements	<i>Quercus glauca</i> , <i>Q. lamellose</i> , <i>Q. leucotrichophora</i> , <i>Q. semecarpifolia</i>	Chilling and changing phenology windows are shortened or disrupted by strong winter/spring warming.	Zeng <i>et al.</i> , 2023, Panda <i>et al.</i> , 2021
6.Soil Temperature & Moisture Changes	Early root/shoot activity; delayed development under drought	<i>Q. semecarpifolia</i> , <i>Betula utilis</i> , <i>Rhododendron arboreum</i>	Heated soil promotes early emergence, root sprouting.	Farahin <i>et al.</i> , 2024
7. Elevation & Microclimate Shifts	Species shift upslope; local timing variability	<i>Abies pindrow</i> , <i>Abies spectabilis</i> , <i>Betula utilis</i> , <i>Rhododendron arboreum</i> , <i>R. campanulatum</i>	Tree species move to cooler elevations; slope, aspect, and wind affect the timing of occurrences.	Feldmeier <i>et al.</i> , 2020, Crepaz <i>et al.</i> , 2024, Mishra <i>et al.</i> , 2024
8.Biotic Interactions with Climate Change	Pollinator mismatches; pest/disease outbreaks	<i>Quercus glauca</i> , <i>Q. lamellose</i> , <i>Q. leucotrichophora</i>	Flowers may blossom before pollinators become active.	Gérard <i>et al.</i> , 2020, Feldmeier <i>et al.</i> , 2020,

		<i>a, Q. semecarpifolia</i>	Warming promotes pests and diseases.	
9. Day length	Prolonged daylength, affects initiating bud growth, flowering time.	<i>Betula utilis</i> , <i>Rhododendron arboreum</i> , <i>R. campanulatum</i> , <i>Shorea robusta</i> , <i>Sapindus mukorossi</i>	Delayed Bud growth and flowering time	Lang <i>et al.</i> , 2024, Panda <i>et al.</i> 2021

One of the most significant environmental elements influencing forest phenology in the Himalayas and surrounding areas is rising temperatures. Many plants, including *Abies pindrow*, *Abies spectabilis*, *Betula utilis*, *Bauhinia variegata*, *Pinus roxburghii* and *Acacia catechu*, experience early budburst, leafing and blooming when the temperature rises. Despite the buildup of heat units, warmer winters frequently lead to insufficient chilling times, which might postpone bud break (Chauhan *et al.*, 2025; Kumar *et al.*, 2024).

The timing of phenophases in alpine and subalpine species, such as *Rhododendron arboreum* and *Myrica esculenta*, is also significantly influenced by changes in snowfall and snowmelt patterns. Reproductive cycles have been demonstrated to be impacted by monsoon variability, including variations in commencement, length, and intensity. While severe rainfall and storms can physically harm flowers and fruits, reducing reproductive success, delayed or decreased rainfall can result in poor blooming and fruiting in species like *Bauhinia variegata* and *Myrica esculenta* (Meghwal *et al.*, 2018; Chand *et al.*, 2017). For species like *Quercus leucotrichophora*, *Betula utilis* and *Rhododendron arboreum*, extreme climatic conditions including drought, late frost and heatwaves further impair seed viability and harm tissues or fruits. Heatwaves cause early leaf flushing while increasing physiological stress, late frost damages young tissues and drought limits fruit set (Augsburger *et al.*, 2011; Chand *et al.*, 2017; Singh *et al.*, 2023). *Quercus glauca*, *Q. lamellöse*, *Q. leucotrichophora* and *Q. semecarpifolia* have seen disruptions in their dormancy and chilling needs due to seasonal warming trends, especially in the winter and spring. Unpredictable budburst and modified blooming sequences are caused by the constriction of cooling and phenological windows (Zeng *et al.*, 2023; Panda *et*

al., 2021). Similar to this, changes in soil moisture and temperature have a direct impact on the growth of roots and shoots. For example, warm soils promote early root activity and sprouting in *Rhododendron arboreum*, *Betula utilis* and *Q. semecarpifolia*, but dryness postpones overall growth and development (Farahin *et al.*, 2024).

Phenological responses are also significantly influenced by elevation and microclimate gradients, species like *Rhododendron arboreum*, *Betula utilis*, *Abies pindrow*, *Abies spectabilis* etc. In reaction to global warming, *campanulatum* are moving their range upslope in search of cooler habitats. Micro-scale fluctuations in the timing of phenological events are also caused by local variations in slope, aspect and wind exposure (Feldmeier *et al.*, 2020; Crepaz *et al.*, 2024; Mishra *et al.*, 2024). Under shifting climates, biotic interactions are equally important; in *Quercus glauca*, *Q. Lamellose*, *Q. Q* and *leucotrichophora*. While warming encourages pest and disease outbreaks that threaten reproductive success and leaf quality, mismatches between blooming and pollinator activity are becoming apparent in *semecarpifolia* (Gérard *et al.*, 2020; Feldmeier *et al.*, 2020). Lastly, phenological signals in a variety of species, including *Betula utilis*, *Rhododendron arboreum*, *R. campanulatum*, *Shorea robusta* and *Sapindus mukorossi*, are still influenced by photoperiod or day duration. In certain areas, longer days alter the start of bud development and blooming, causing phenophases to be delayed in comparison to past patterns (Lang *et al.*, 2024). Overall, these observations collectively underscore that forest tree phenology in the Himalayas is undergoing significant shifts under the influence of multiple, interacting climatic factors—rising temperatures, altered precipitation and snow regimes and microclimatic variability—posing profound implications for species distribution, forest productivity and ecosystem stability.

Conclusion

The Himalayan area, with its unique biodiversity and ecological significance, is undergoing fast alteration as a result of climate change. The most apparent and sensitive markers of this transition are phenological alterations in tree species, which show how warming temperatures, altering precipitation regimes, and altered snowmelt patterns are transforming forest ecosystems. Evidence from multifunctional and ecologically dominating species demonstrates improvements in leaf emergence, varied flowering responses, changed fruiting patterns and upward treeline migration, all of which testify to climatic variability's substantial effect on plant life cycles. These changes go beyond individual species, influencing forest

composition, pollination success, regeneration cycles and ecological services that benefit both biodiversity and human groups. The Himalayan people's livelihoods, which are inextricably linked to the seasonal cycles of forests for feed, fuelwood, medicinal herbs and agriculture, are under growing threat. Furthermore, the lack of synchronization between phenological events and ecological interactions has the potential to disrupt long-standing ecological balances, putting long-term sustainability at risk. To overcome these challenges, an integrated approach is necessary, with long-term phenological monitoring, predictive climate-ecosystem modelling, and adaptive forest management taking precedence. Similarly significant are community-based conservation strategies and legal frameworks that improve climate resilience in forestry and livelihoods. In summary, phenological fluctuations observed in Himalayan trees are more than just biological changes; they are markers of climate change and warning indications of ecological vulnerability. Recognizing and responding to these changes is vital not only for maintaining Himalayan biodiversity, but also for safeguarding the ecological and socioeconomic stability of one of the world's most fragile but critical mountain ecosystems.

References

- Augspurger, C. K. (2011). Frost damage and its cascading negative effects on *Aesculus glabra*. *Plant Ecology*, 212(7), 1193–1203. [10.1007/s11258-011-9897-z](https://doi.org/10.1007/s11258-011-9897-z)
- Bhutiyan MR, Kale VS, Pawar NJ (2007) Long-term trends in maximum, minimum and mean annual air temperatures across the northwestern Himalaya during the twentieth century. *Clim Chang* 85:159–177.
- Brohan P, Kennedy JJ, Harris I, Tett SFB, Jones PD (2006) Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. 111; D12. <https://doi.org/10.1029/2005JD006548>
- Chand, D. B., Poudyal, k. ,Jha , P.K., (2017) . Shift in leaf phenology of three Himalayan oak species: Role of wood water properties. *Ecoprint* 24:29-36.
- Chauhan, V., Mohammed, H., Sharma, J., Parmar, S., Chand, T., Pal Panwar, V., & Bala, N. (2025). Phenological responses of key tree species to climatic variables in Garhwal Himalaya. *Journal of Sustainable Forestry*, 713-728 (44). <https://doi.org/10.1080/10549811.2025.2525193>
- Crepaz, H., Quaglia, E., Lombardi, G., Lonati, M., Rossi, M., Ravetto Enri, S., Dullinger, S., Tappeiner, U., & Niedrist, G. (2024). Phenological responses of alpine snowbed

- communities to advancing snowmelt. *Ecology and Evolution*, 14(7).
<https://doi.org/10.1002/ece3.11714>
- Dash SK, Jenamani RK, Kalsi SR, Panda SK (2007) Some evidence of climate change in twentieth-century India. *Clim Chang* 85:299–321
- Dimri AP, Dash SK (2012) Wintertime climatic trends in the western Himalayas. *Clim Chang* 111(3):775–800.
- Diodato N, Bellocchi G, Tartari G (2012) How do Himalayan areas respond to global warming? *Int J Climatol* 32:975–982.
- Farahin, S., & Patah, A. (2024). Influence of soil temperature on root development and microbial diversity in paddy fields: A comprehensive review. *Trends in Ecology & Evolution*, 2(4), 1–9 [10.62622/TEIEE.024.2.4.01-09](https://doi.org/10.62622/TEIEE.024.2.4.01-09)
- Feldmeier, S., Schmidt, B. R., Zimmermann, N. E., & Veith, M. (2020). Shifting aspect or elevation? The climate change response of ectotherms in a complex mountain topography. *Diversity and Distributions*, 26(3), 1483–1495. [10.1111/ddi.13146](https://doi.org/10.1111/ddi.13146)
- Gérard, M., Vanderplanck, M., Wood, T., & Michez, D. (2020). Global warming and plant–pollinator mismatches. *Emerging Topics in Life Sciences*, 4(1), 77–86. [10.1042/ETLS20190139](https://doi.org/10.1042/ETLS20190139)
- Kalra, A., Goel, S., & Elias, A. A. (2023). Understanding role of roots in plant response to drought: Way forward to climate-resilient crops. *Plant Genome*, 16(3). <https://doi.org/10.1002/tpg2.20395>
- Kumar, S., & Khanduri, V. P. (2024). Impact of climate change on the Himalayan alpine treeline vegetation. *Heliyon*, 10(23), e40797.
- Lang, W., Qian, S., & Chen, X. (2024). Daylength predominates the bud growth initiation of winter deciduous forest trees in the monsoon region of China. *Frontiers in Plant Science*, 14, 1327509 <https://doi.org/10.3389/fpls.2023.1327509>.
- Meghwal PR, Kumar P & Singh D. 2018. Climate variability during flowering and fruiting reduces fruit yield of ber (*Ziziphus mauritiana*) in Western Rajasthan. *Journal of Agriculture and Ecology*, 6: 31-38 .
- Mishra, A., Jugran, H. P., Sekar, K. C., & Talukdar, G. (2024). Plant phenological shifts in the Indian Himalayan region. In *Warming mountains*. Springer (85–104). [10.1007/978-3-031-62197-0_5](https://doi.org/10.1007/978-3-031-62197-0_5)

- Mishra, A., Pant Jugran, H., Sekar, K. C., & Talukdar, G. (2024). Plant phenological shifts in the Indian Himalayan region. In *Warming Mountains* (pp. 85–104). Springer
- Panda, S., Bhardwaj, D. R., Sharma, P., Handa, A. K., & Kumar, D. (2021). Impact of climatic patterns on phenophase and growth of multi-purpose trees of north-western mid-Himalayan ecosystem. *Trees, Forests and People*, 6, 100143. <https://doi.org/10.1016/j.tfp.2021.100143>
- Rana, N., Manish, K., & Pandit, M. K. (2025). Effect of climate change on the flowering phenology of *Rhododendron arboreum* Sm. in the Western Himalaya. *Journal of Asia-Pacific Biodiversity*, 18(2), 197–203. <https://doi.org/10.1016/j.japb.2024.10.004>
- Singh, R., Rawat, M., Chand, T., Tripathi, S. K., & Pandey, R. (2023). Phenological variations in relation to climatic variables of moist temperate forest tree species of western Himalaya, India. *Heliyon*, 9(10), e16563. <https://doi.org/10.3126/eco.v24i0.20644>
- Tripathi, A. K., Pandey, P. C., & Sharma, J. K. (2022). Climate change and its impact on forest of Indian Himalayan region: A review. In *Climate change* (207–222). Springer. [10.1007/978-3-030-92782-0_10](https://doi.org/10.1007/978-3-030-92782-0_10)
- Zeng, X., Du, Y., & Vitasse, Y. (2023). *Untangling winter chilling and spring forcing effects on spring phenology of subtropical tree seedlings*. *Agricultural and Forest Meteorology*. Advance online publication. 335, (15) 109456 <https://doi.org/10.1016/j.agrformet.2023.109456> 

HEAVY METAL STRESS AND BIOREMEDIATION IN PLANT

Article ID: AG-V05-I12-42

***A.K. Padhiyar¹ and Dileep Kumar²**

Anand Agricultural University, Anand- 388110, Gujarat, India

*Corresponding Author Email ID: arpitapadhiyar3097@gamil.com

Introduction

Heavy metals, such as cadmium, lead, chromium, copper, nickel and mercury are major environmental pollutants, particularly in areas with high anthropogenic pressure and accumulated in soils. Heavy metal accumulation in soils is of great concern in agricultural production due to the adverse effects on food safety and marketability, crop growth due to phytotoxicity, and environmental health of soil organisms. The influence of plants and their metabolic activities affect the geological and biological redistribution of heavy metals through pollution of the air, water and soil. This not only results in significant crop yield losses but also raises health risks.

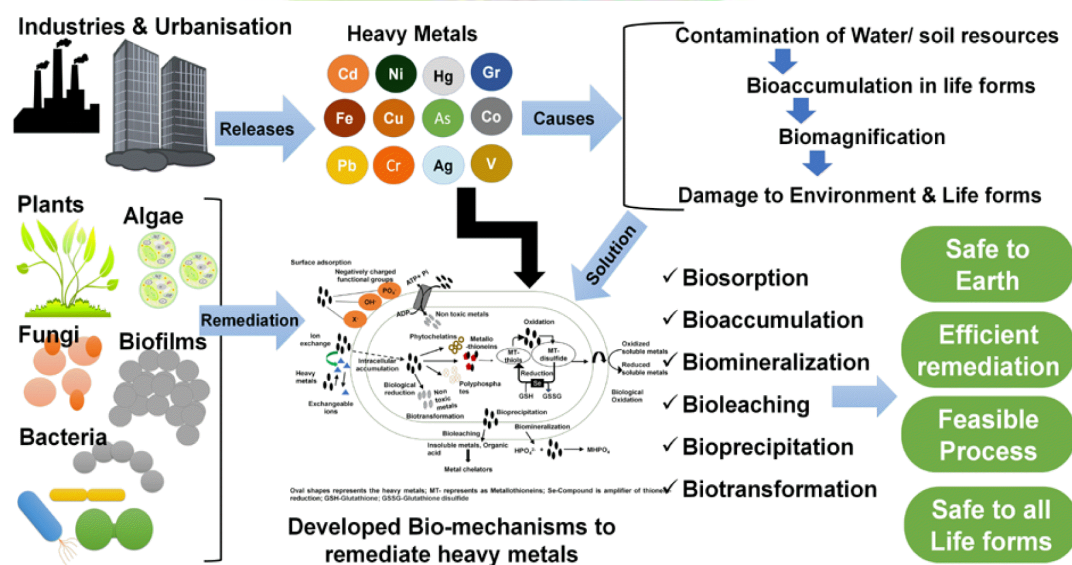


Figure 1: graphical representation of heavy metal accumulation and their bio remediation

Microbial Remediation of Heavy Metals for Plant Growth Promotion

Remediation of heavy metals is necessary for the protection and conservation of the environment (Glick, 2010). For the elimination of heavy metals from the environment, numerous physicochemical and biological techniques have been adopted. Physicochemical techniques are rapid but are regarded as challenging due to the cost involved and technical complexity. They also cause adverse effects on soil physical, chemical, and biological properties, and lead to secondary pollution (Glick, 2010; Sheoran et al., 2011; Ali et al., 2013; Ullah et al., 2015).

Biological remediation is considered as the most effective method of toxic metal removal as these are natural, environment friendly, low cost, and high societal acceptance technologies (Doble and Kumar, 2005). This is feasible because microorganisms have developed many resistance mechanisms for survival in the presence of toxic heavy metals in their environment (Thassitou and Arvanitoyannis, 2001; Mustapha and Halimoon, 2015). Microbes also enhance bioavailability of metals from soil by chelation, acidification, and precipitation as, for example, organic acids released by microbes and plant roots lower the soil pH and helps in sequestration of metal ions (Mishra et al., 2017).

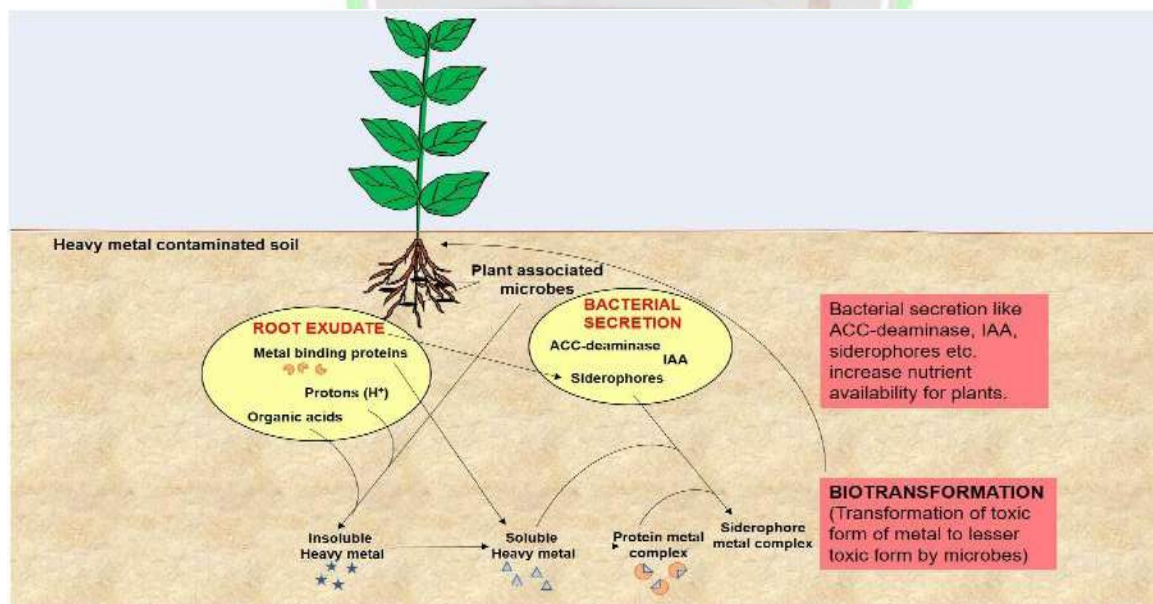


Figure 2. A model of microbial remediation processes involved in heavy metal removal elaborates modulation of plant growth and alteration of soil physicochemical properties by root exudates and bacterial secretion to enhance metal bioavailability and biotransformation that leads to rapid detoxification and/or removal of heavy metal from soil.

Table 1. Efficiency of different bacterial strains in removal of heavy metals

Bacterial Strain	Heavy metals	Mechanism	Removal Efficiency (%)
Shewanella putrefaciens	Cd	Biosorption	86.5%
Bacillus thuringiensis	Hg	Biosorption	62%
Enterobacter cloacae	Hg (II)	Bioreduction	Up to 81%
Bacillus cereus	Cr	Biosorption	81%
Cellulosimicrobium sp. (KX710177)	Pb	Biosorption	99.3%
Bacillus sp. SFC	Cr	Biosorption	80%
Acinetobacter sp. B9	Ni	Biosorption	69%
Klebsiella sp. USL2D	Pb	Biosorption	97.13%
Streptomyces sp.	Pb	Biosorption	83.4%
Desulfovibrio desulfuricans	Zn	Biosorption	100%
Pseudomonas aeruginosa FZ-2	Hg	Biosorption	99.7%
Pseudomonas aeruginosa RW9	Cr	Bioaccumulation	90%
Streptomyces rochei ANH	Cr (VI)	Biosorption	86%

Remediation of Heavy Metals by Bacteria

Bacteria are the most crucial microbial organisms used for the remediation of heavy metal contaminated soils (Chen et al., 2015). Bacteria alleviate heavy metal ion toxicity by immobilizing, mobilizing, uptake, and transformation of heavy metals (Hassan et al., 2017). Several studies have been reported where PGPR act as potential elicitors for abiotic stress tolerance including heavy metal tolerance (Dary et al., 2010; Tiwari et al., 2016, 2017b). Heavy-metal-tolerant PGPR including *Bacillus*, *Pseudomonas*, *Streptomyces*, and *Methylobacterium* have the potential to improve growth and production of crops by reducing the detrimental effects of heavy metals (Sessitsch et al., 2013).

We studied during *rabi* season of the year 2021-22 in net house of the Micronutrient Research Centre, Anand Agricultural University to evaluate the effect of bacterial consortium for alleviating heavy metals toxicity in spinach. Used of two factors in Factor I: Control (without bacterial inoculation), Bacterial inoculation (consortium of *Pseudomonas azotoformans*, *Bacillus*

infantis, *Bacillus megaterium* and *Micrococcus terreus*), FYM (5 t/ ha) and Factor II: Control (Without heavy metals), Cd @1.5, 3.0, 6.0 mg/kg, Cr & Pb @ 25, 50, 100 mg/kg

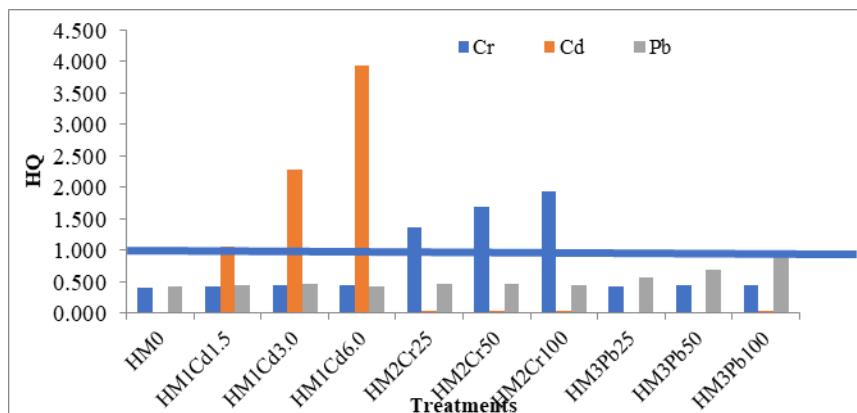


Figure 3: Effect of heavy metal toxicity at different level on shoot and root growth of spinach

Results of present study revealed that Cr treatments even at low level and Cd and Pb at high level induces a significant reduction in all growth parameters *i.e.*, shoot and root weight, shoot and root length of in spinach crop. Increasing concentrations of Cd, Cr and Pb in soil resulted also in a corresponding increase of respective metal in the shoot and root of spinach and in soil as well as presence of bacterial inoculation and FYM promoted growth of plants in terms of shoot and root weight, shoot and root length in spinach plants subjected to application of different rate of Cd, Cr and Pb metals and reduced the content of respective heavy metals in spinach. Looking at the consequences of heavy metals on different components of food chain, at higher rate of heavy metals (Cd, Cr, and Pb), greater accumulation of heavy metals in shoot and root is a major concern for human health due to a higher consumption rate.



Comparison of Observed hazard quotient (HQ) of Cr, Cd and Pb for human



References

- Ali, H., Khan, E., and Sajad, M. A. (2013). Phytoremediation of heavy metals-Concepts and applications. *Chemosphere* 91, 869–881. doi: 10.1016/j.chemosphere.2013.01.075.
- Chen, M., Xu, P., Zeng, G., Yang, C., Huang, D., and Zhang, J. (2015). Bioremediation of soils contaminated with polycyclic aromatic hydrocarbons, petroleum, pesticides, chlorophenols and heavy metals by composting: applications, microbes and future research needs. *Biotechnol. Adv.* 33, 745–755. doi: 10.1016/j.biotechadv.2015.05.003.
- Dary, M., Chamber-Pérez, M. A., Palomares, A. J., and Pajuelo, E. (2010). “In situ” phytostabilisation of heavy metal polluted soils using *Lupinus luteus* inoculated with metal resistant plant-growth promoting rhizobacteria. *J. Hazard. Mater.* 177, 323–330. doi: 10.1016/j.jhazmat.2009.12.035.
- Doble, M., and Kumar, A. (2005). *Biotreatment of Industrial Effluents*. Oxford: Butterworth-Heinemann, 19–38. doi: 10.1016/B978-075067838-4/50004-X
- Glick, B. R. (2010). Using soil bacteria to facilitate phytoremediation. *Biotechnol. Adv.* 28, 367–374. doi: 10.1016/j.biotechadv.2010.02.001.
- Hassan, T. U., Bano, A., and Naz, I. (2017). Alleviation of heavy metals toxicity by the application of plant growth promoting rhizobacteria and effects on wheat grown in saline sodic field. *Int. J. Phytoremediation* 19, 522–529. doi: 10.1080/15226514.2016.1267696.
- Mishra, J., Singh, R., and Arora, N. K. (2017). Alleviation of heavy metal stress in plants and remediation of soil by rhizosphere microorganisms. *Front. Microbiol.* 8:1706. doi: 10.3389/fmicb.2017.01706.

- Mustapha, M. U., and Halimoon, N. (2015). Screening and isolation of heavy metal tolerant bacteria in industrial effluent. *Procedia Environ. Sci.* 30, 33–37. doi: 10.1016/j.proenv.2015.10.006.
- Padhiyar, A. K., Dileep Kumar, Patel, K. C., and Patel, V. J. (2025). Efficacy Of Heavy Metals-Tolerant Plant Growth Promoting Bacterial Consortium for Alleviating Cadmium Toxicity in Spinach. *Plant Archives* Vol. 25, Supplement 1, 2025 pp. 1320-1325.
- Parasakthi, J., Chandrani, D., Vijayaraghavan, R., Muthusivaramapandian, M. (2023). Trends in Bioremediation of Heavy Metal Contaminations. *Environmental Engineering Research* 2023; 28(4): 220631.
- Sessitsch, A., Kuffner, M., Kidd, P., Vangronsveld, J., Wenzel, W. W., Fallmann, K., et al. (2013). The role of plant-associated bacteria in the mobilization and phytoextraction of trace elements in contaminated soils. *Soil Biol. Biochem.* 60, 182–194. doi: 10.1016/j.soilbio.2013.01.012.
- Thassitou, P., and Arvanitoyannis, I. (2001). Bioremediation: a novel approach to food waste management. *Trends Food Sci. Technol.* 12, 185–196. doi: 10.1016/S0924-2244(01)00081-4.
- Tiwari, S., Lata, C., Chauhan, P. S., and Nautiyal, C. S. (2016). *Pseudomonas putida* attunes morphophysiological, biochemical and molecular responses in *Cicer arietinum* L. during drought stress and recovery. *Plant Physiol. Biochem.* 99, 108–117. doi: 10.1016/j.plaphy.2015.11.001.
- Tiwari, S., Prasad, V., Chauhan, P. S., and Lata, C. (2017b). *Bacillus amyloliquefaciens* confers tolerance to various abiotic stresses and modulates plant response to phytohormones through osmoprotection and gene expression regulation in rice. *Front. Plant Sci.* 8:1510. doi: 10.3389/fpls.2017.01510.
- Ullah, A., Heng, S., Munis, M. F. H., Fahad, S., and Yang, X. (2015). Phytoremediation of heavy metals assisted by plant growth promoting (PGP) bacteria: a review. *Environ. Exp. Bot.* 117, 28–40. doi: 10.1016/j.envexpbot.2015.05.001.

TIMING THE TOXINS: CIRCADIAN RHYTHM IN ENVIRONMENTAL STRESS AND DETOXIFICATION

Article ID: AG-VO5-I12-43

Barad Harsidhdhi*, Krishna Chavda and Rudrik Dave

Master of Science in Zoology, Gujarat University, India

*Corresponding Author Email ID: harubarad12@gmail.com

Abstract

The circadian clock put together daily timing in physiology, metabolism, and gene expression, aligning internal biology with environmental cycles (Reppert & Weaver, 2002; Takahashi *et al.*, 2008). Emerging evidence shows that circadian regulation also plays a central role in how organisms handle environmental stressors and toxins (Zheng *et al.*, 2020; Bass & Lazar, 2016). Disruption of circadian timing (chronodisruption) can impair detoxification pathways, increase cellular vulnerability to pollutants, and exacerbate disease outcomes (Mana *et al.*, 2021; Curtis *et al.*, 2014). This review synthesizes current knowledge on how the circadian system modulates detoxification, oxidative defense, and stress responses, and how its disruption contributes to environmental toxicity (Sahar & Sassone-Corsi, 2009).

Keywords

Circadian rhythm, chronodisruption, detoxification, xenobiotics, environmental toxins.

Introduction

Life on Earth has always followed a 24-hour cycle of day and night. To live in tune with this rhythm, almost all living organisms have developed an internal biological clock called the circadian rhythm (Dunlap *et al.*, 2004). This clock helps the body know when to sleep, eat, repair itself, and protect against damage (Takahashi, 2017).

Inside every cell, special clock genes such as CLOCK, BMAL1, PER, and CRY keep this rhythm running. They switch other genes on and off at different times of the day, regulating important processes like metabolism, cell growth, and immune function (Ko & Takahashi, 2006; Zhang *et al.*, 2014).

Recent studies show that the circadian clock also helps the body cope with environmental stress such as pollution, chemicals, ultraviolet light, and other toxins (Gibbs *et al.*, 2012; Masri & Sassone-Corsi, 2010). The body removes these harmful substances through detoxification enzymes, and their activity changes over the course of the day (Bollinger *et al.*, 2011; Zhang *et al.*, 2009). This means that some toxins can be more harmful at certain times, a concept known as chronotoxicology (Dallmann *et al.*, 2014).

The ability of cells to cope with oxidative stress the harm brought on by reactive oxygen molecules is similarly regulated by the circadian rhythm (Rey & Reddy, 2013). The body's defense and repair mechanisms deteriorate when its internal clock is thrown off balance by things like working shifts, being exposed to light at night, or getting little sleep (Scheer *et al.*,



Figure 1: The Circadian Rhythm Model

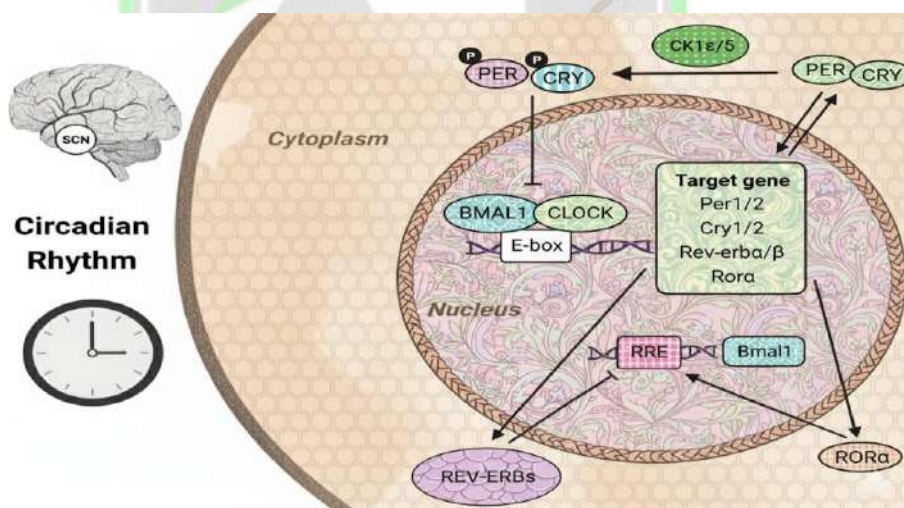
2009; Wang *et al.*, 2021). This can eventually result in cancer, metabolic issues, and inflammation (Papagiannakopoulos *et al.*, 2016). Simply said, the circadian rhythm aids in the body's ability to maintain equilibrium, heal injuries, and combat poisons when they arise (Bass & Takahashi, 2010). By comprehending this relationship, physicians may create more effective therapies and determine the best time of day to provide medications a technique known as chronotherapy (Smolensky *et al.*, 2019).

Environmental Stressors and Circadian Disruption

Environmental stressors such as air pollution, chemical pollutants, and light pollution disrupt circadian rhythms and contribute to physiological imbalance (Fonken & Nelson, 2014; Kantermann *et al.*, 2012). Oxidative stress, inflammation, and epigenetic alterations are key mechanisms that impair circadian control (Tahara *et al.*, 2017; Papagiannakopoulos *et al.*, 2016). Chronic exposure leads to phase shifts or amplitude damping in rhythmic detoxification pathways, resulting in higher susceptibility to toxins (Mana *et al.*, 2021).

Circadian Regulation of Detoxification and Stress Response

Detoxification pathways (Phase I, II, and III) show circadian regulation in gene expression and enzyme activity (Zhou *et al.*, 2016; Zhang *et al.*, 2009). Core clock components BMAL1 and CLOCK modulate PAR bZip transcription factors, influencing cytochrome P450, glutathione S- Figure 2: Molecular Mechanism of the Circadian Clock transferase, and ABC transporter expression (Gachon *et al.*, 2006; Kornmann *et al.*, 2007). The clock also interacts with NRF2, PXR, CAR, and PPARs to coordinate antioxidant and xenobiotic responses (Weger *et al.*, 2019; Zmrzljak & Rozman, 2012).



Consequences of Chronodisruption Under Environmental Stress

Chronodisruption increases vulnerability to pollutants, oxidative stress, and inflammation, aggravating chronic diseases like cancer, cardiovascular disorders, and metabolic syndromes (Papagiannakopoulos *et al.*, 2016; Curtis *et al.*, 2014). Organ-specific effects include liver impairment, lung inflammation, and skin damage due to disrupted detoxification timing (Mana *et al.*, 2021; Zhang *et al.*, 2014).

Conceptual Framework: Chronotoxicology

Chronotoxicology integrates timing and exposure to understand how the circadian phase influences toxicity (Dallmann *et al.*, 2014; Zhang *et al.*, 2009). Key ideas include time-of-day-dependent toxicity, vulnerability windows, and chronotherapeutic mitigation strategies that align protective mechanisms with exposure timing (Smolensky *et al.*, 2019).

Potential Chronotherapeutic and Preventive Strategies

Phase-targeted dosing and drug administration (Smolensky *et al.*, 2019)

Controlled lighting and sleep hygiene (Fonken & Nelson, 2014)

Time-restricted feeding (Longo & Panda, 2016)

Chrono-modulating pharmacological agents (Mana *et al.*, 2021)

Lifestyle alignment with circadian timing (Bass & Lazar, 2016)

Conclusion

The circadian clock is a central regulator of detoxification, stress defense, and repair. Environmental toxins can both disturb circadian timing and exploit its vulnerabilities. Recognizing and harnessing temporal dynamics could unlock new strategies for mitigating pollutant harm and guiding chronotherapeutic interventions (Sahar & Sassone-Corsi, 2009; Bass & Lazar, 2016).

References

- Bass, J., & Lazar, M. A. (2016). Circadian time signatures of fitness and disease. *Science*, 354(6315), 994–999. <https://doi.org/10.1126/science.aaf6806>
- Bollinger, T., Gachon, F., & Schibler, U. (2011). Circadian regulation of drug-metabolizing enzymes. *Pharmacological Research*, 63(4), 259–266. <https://doi.org/10.1016/j.phrs.2010.12.007>
- Coca-Ruiz, V., & Boy-Ruiz, D. (2025). Timing is everything: The fungal circadian clock as a master regulator of stress response and pathogenesis. *Stresses*, 5(3), 47. <https://doi.org/10.3390/stresses5030047>
- Curtis, A. M., Bellet, M. M., Sassone-Corsi, P., & O'Neill, L. A. (2014). Circadian clock proteins and immunity. *Immunity*, 40(2), 178–186. <https://doi.org/10.1016/j.immuni.2014.01.007>
- Dallmann, R., Viola, A. U., Tarokh, L., Cajochen, C., & Brown, S. A. (2014). The human circadian metabolome. *Proceedings of the National Academy of Sciences*, 111(8), 1–6. <https://doi.org/10.1073/pnas.1322174111>

- Fonken, L. K., & Nelson, R. J. (2014). The effects of light at night on circadian clocks and metabolism. *Endocrine Reviews*, 35(4), 648–670. <https://doi.org/10.1210/er.2013-1051>
- Gachon, F., Olela, F. F., & Schibler, U. (2006). The mammalian circadian timing system and the regulation of drug metabolism. *Journal of Clinical Investigation*, 116(3), 748–755. <https://doi.org/10.1172/JCI29256>
- Gibbs, J., & Davidson, A. J. (2012). The circadian clock and the regulation of drug metabolism. *Pharmacology & Therapeutics*, 133(2), 196–205. <https://doi.org/10.1016/j.pharmthera.2011.09.004>
- Ko, C. H., & Takahashi, J. S. (2006). Molecular components of the mammalian circadian clock. *Human Molecular Genetics*, 15(R2), R271–R277. <https://doi.org/10.1093/hmg/ddl207>
- Kornmann, B., Schaad, O., Bujard, H., & Schibler, U. (2007). System-driven synchronization of a circadian clock in mammalian cells. *Nature*, 437(7059), 481–486. <https://doi.org/10.1038/nature03903>
- Mana, M., & Reddy, A. B. (2021). Circadian rhythms and detoxification. *Free Radical Biology and Medicine*, 163, 1–9. <https://doi.org/10.1016/j.freeradbiomed.2021.02.019>
- Masri, S., & Sassone-Corsi, P. (2010). The circadian clock: Metabolic cycles and endocrine circuits. *Nature Medicine*, 16(7), 755–767. <https://doi.org/10.1038/nm.2183>
- Papagiannakopoulos, T., Bauer, M. R., Davidson, S. M., & Rabinowitz, J. D. (2016). Circadian rhythm disruption promotes lung tumorigenesis. *Cell Metabolism*, 24(2), 324–331. <https://doi.org/10.1016/j.cmet.2016.06.020>
- Reppert, S. M., & Weaver, D. R. (2002). Coordination of circadian timing in mammals. *Nature*, 418(6901), 935–941. <https://doi.org/10.1038/nature00965>
- Sahar, S., & Sassone-Corsi, P. (2009). Circadian clock and breast cancer: A molecular link. *Cell Cycle*, 8(16), 2493–2497. <https://doi.org/10.4161/cc.8.16.9443>
- Scheer, F. A., Hilton, M. F., & Mantzoros, C. S. (2009). Adverse metabolic and cardiovascular consequences of circadian misalignment. *Proceedings of the National Academy of Sciences*, 106(11), 4453–4458. <https://doi.org/10.1073/pnas.0808180106>
- Smolensky, M. H., & Lamberg, L. (2019). Chronobiology and chronotherapy of cancer: Principles and applications. *Cancer Journal*, 25(6), 1–10. <https://doi.org/10.1097/PPO.0000000000000393>

- Takahashi, J. S. (2017). Transcriptional architecture of the mammalian circadian clock. *Nature Reviews Genetics*, 18(3), 164–179. <https://doi.org/10.1038/nrg.2016.150>
- Takahashi, J. S., & Zatz, M. (2008). Molecular components of the circadian clock. *Cell*, 134(3), 381–384. <https://doi.org/10.1016/j.cell.2008.07.001>
- Wang, Y., & Liu, Y. (2021). Circadian rhythms and oxidative stress in aging and age-related diseases. *Antioxidants*, 10(11), 1–16. <https://doi.org/10.3390/antiox10111741>
- Zhang, R., & Kay, S. A. (2014). Clocks not winding down: Unraveling the mechanisms of the circadian clock. *Science*, 345(6196), 1247–1251. <https://doi.org/10.1126/science.1254596>
- Zheng, X., & Zhang, Y. (2020). Circadian rhythms and environmental stressors: Implications for health and disease. *Frontiers in Physiology*, 11, 1–15. <https://doi.org/10.3389/fphys.2020.00768>



Volume: 05 Issue No: 12

NANOPLANKTON: THE TINY CLIMATE WARRIORS DRIVING EARTH'S NATURAL CARBON PUMP

Article ID: AG-VO5-I12-44

Ilakkiya S*

Department of Aquatic Environment Management, Dr. M.G.R Fisheries College and Research
Institute, Ponneri, Tiruvallur, Tamil Nadu - 601 204, India.

*Corresponding Author Email ID: IlakkiyaS12@gmail.com

Abstract

Nanoplankton, microscopic photosynthetic organisms measuring 2–20 μm , play a vital yet often overlooked role in regulating Earth's climate. Nanoplankton absorb dissolved carbon dioxide through photosynthesis. They form the base of marine food webs and drive the 'biological carbon pump,' a process that transports carbon to the deep ocean for long-term storage. They do this by taking in dissolved CO_2 through photosynthesis. They are a major part of global primary production because they are small and can take in nutrients quickly, which lets them thrive in warm, nutrient-poor (oligotrophic) oceans. Some species, like coccolithophores, make calcium carbonate plates that speed up the sinking of particles, which helps carbon leave the ocean. In Indian waters, such as the Arabian Sea, the Bay of Bengal, and coastal island ecosystems, a wide range of nanoplankton communities help fisheries, keep marine productivity high, and help with carbon sequestration in the region. To fight climate change, blue carbon projects, and long-term management of coastal ecosystems, it's important to know what their ecological roles are.

Keywords: Nanoplankton, Biological carbon pump, Carbon sequestration, Coccolithophores, Indian marine ecosystems, Climate change.

Introduction: Small Size, Big Impact

When we think of how to tackle climate change, we often think of forests, renewable energy, or devices that take carbon out of factories. Nanoplankton, on the other hand, is a lesser-known climate hero that lives deep in the world's waters. These small microbes are a vital component of the marine phytoplankton ecosystem and play a big role in the biological carbon pump, which is a natural process that sucks CO_2 from the air into the ocean and keeps it there for

hundreds of years. Nanoplankton are very small, but they make up a significant portion of the world's primary production. Because of this, they are crucial for the balance of carbon in the globe, marine food webs, and fisheries. They are the "engines" of ocean ecosystems because they can make carbon, exist in locations with low nutrients, and keep up high productivity.

Nanoplankton

Nanoplankton, which are between 2 and 20 micrometers in size, are small but very important photosynthetic organisms. They include groupings like nanoflagellates, small diatoms, coccolithophores, mixotrophic protists, and cyanobacteria like *Synechococcus*. Even though they are small, they are very important for world's primary production and the carbon cycle. These organisms are especially well suited to oligotrophic (nutrient-poor) environments, which make up a lot of the world's open oceans. They do well in places where nutrients are hard to find because they have good ways of getting nutrients and a high surface-area-to-volume ratio. As the oceans get warmer and more stratified, nanoplankton are likely to become even more competitive. This will make them even more crucial for marine productivity and carbon sequestration in the future.

Nanoplankton: Functions as a Carbon Pump

Nanoplankton acts as a natural carbon pump through three major processes:

1. Carbon Fixation through Photosynthesis

Nanoplankton absorb in carbon dioxide (CO_2) from the water around them and metabolize it into organic carbon through photosynthesis. This process not only lowers the level of CO_2 in the surface ocean and atmosphere, but it also builds the foundation of marine food webs. The fixed carbon supports a lot of marine life, such as:

- **Zooplankton:** Which graze on nanoplankton and transfer energy to higher trophic levels.
- **Fish larvae and small pelagic fish:** Which rely on nanoplankton-rich waters for their early development.
- **Higher trophic levels:** Including commercially important fish species, seabirds, and marine mammals.

In oligotrophic (low-nutrient) parts of the ocean, like the subtropical gyres that cover large parts of the tropical and subtropical oceans, nanoplankton are the most common type of plankton. In these areas, there aren't enough nutrients, therefore larger phytoplankton aren't as common. Instead, nanoplankton are the main drivers of primary production in these seas. Even though

their individual biomass is modest, their large numbers allow them to make a difference – sometimes making up more than 30-40% of all oceanic primary production.

Nanoplankton also have high surface-area-to-volume ratios, which makes them better at taking in nutrients and lets them thrive in environments with low nutrient levels, where other organisms cannot survive.

2. Export of Carbon to the Deep Ocean

The organic carbon produced by nanoplankton is not confined to the surface layers; a portion of it eventually sinks into the deep ocean, forming an essential component of the **biological carbon pump**. There are many ways that carbon can move vertically:

- **Natural Mortality:** Nanoplankton cells and organic substances get together and slowly sink when they die.
- **Aggregate Formation:** Nanoplankton can form colonies or clumps, which increase the size and density of sinking particles, facilitating their transport to deeper layers.
- **Zooplankton Grazing:** Zooplankton feed on nanoplankton and release carbon-rich fecal pellets, which are dense and sink rapidly, efficiently exporting carbon from surface waters to the ocean interior.

When this carbon is taken to the deep ocean, it can be stored there for decades or even centuries. This keeps it out of the atmosphere and slows down global warming. If this natural carbon export system didn't exist, the amount of CO₂ in the air would be much higher, which would make climate change worse.

The efficiency of the carbon export is influenced by nanoplankton composition, aggregation behavior, and interactions with other planktonic organisms. Recent studies suggest that even small changes in nanoplankton populations can have profound impacts on the efficiency of the biological carbon pump, highlighting their crucial role in Earth's climate system.

3. Production of Calcium Carbonate (in Coccolithophores)

Among nanoplankton, **coccolithophores** are particularly important because they produce microscopic calcite plates called **coccoliths**. These calcium carbonate structures serve multiple ecological and biogeochemical functions:

- **Enhanced Sinking:** Coccoliths add weight to nanoplankton cells and aggregates, increasing their sinking velocity and improving the efficiency of carbon export to the deep ocean.

- **Sequestration of Inorganic Carbon:** When coccoliths sink to deeper layers, they remove not just organic carbon but also inorganic carbon in the form of calcium carbonate, contributing to long-term carbon sequestration.
- **Impact on Ocean Chemistry:** Coccolithophore calcification influences ocean alkalinity and the carbon dioxide buffering capacity of seawater, indirectly affecting atmospheric CO₂ levels.

The dual contribution of coccolithophores to both organic and inorganic carbon export makes them a key component of the oceanic carbon cycle. Seasonal blooms of coccolithophores can dramatically enhance carbon fluxes in specific regions, highlighting the dynamic and significant role of nanoplankton in regulating global climate.

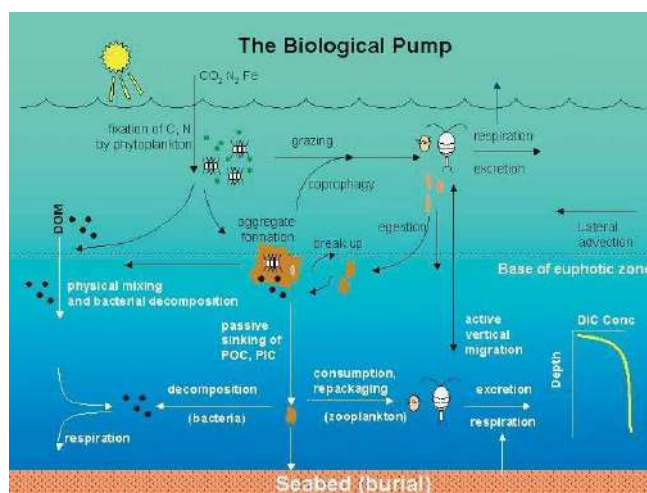


Figure 1. Upper Ocean Carbon Export and the Biological Pump - Scientific Figure on ResearchGate. https://www.researchgate.net/figure/Components-of-the-biological-pump-are-responsible-for-transforming-Dissolved-Inorganic_fig1_262402992

Importance of Nanoplankton

✓ Climate Regulation

By capturing and exporting CO₂, nanoplankton help regulate Earth's climate naturally.

✓ Marine Productivity

Nanoplankton support up to **60% of marine primary production** in some regions, making them essential for marine biodiversity and fisheries.

✓ Food Security

Fish larvae and zooplankton depend on nanoplankton, linking them directly to the sustainability of fisheries and aquaculture.

✓ **Ocean Health Indicators**

Because they respond quickly to environmental changes, nanoplankton are excellent indicators of climate change, nutrient pollution, and ocean warming.

✓ **Carbon Sequestration Services**

As oceans warm and stratify, nanoplankton often outcompete larger phytoplankton, potentially increasing future carbon sequestration capacity.

Nanoplankton in Indian Waters

Indian waters, which include the Arabian Sea, the Bay of Bengal, and many coastal environments, are home to many different and changing nanoplankton groups. These areas are affected by unique monsoonal cycles, upwelling systems, and the flow of freshwater, which create rich environmental gradients that affect the distribution and productivity of nanoplankton. Strong seasonal upwelling in the Arabian Sea makes nutrients more available, which promotes the nanoplankton biomass and a lot of carbon fixation. The Bay of Bengal is more stratified and has more freshwater, yet it still has mixotrophic and nutrient-efficient nanoplankton groups that function well in low-nutrient environments. Coastal estuaries, lagoons and regions with mangroves also have prolific groups of nanoplankton that support local fisheries. However, pollution, eutrophication and warming seas are beginning to alter these communities. To figure out how much carbon is stored in Indian waters, how healthy the ecosystem is, and how well it will adapt to future climatic changes, we need to know how nanoplankton move around.

Climate Change and the Future of Nanoplankton

Climate change is changing the oceans in ways that have a direct impact on the survival, productivity, and ecological importance of nanoplankton. The composition and distribution of these small producers are likely to vary because of rising sea temperatures, changes in stratification and changes in nutrient cycles. While some nanoplankton groups may thrive in warmer, nutrient-poor waters, others-particularly calcifying species-face stress from ocean acidification, which weakens their ability to form protective shells. Such changes could disrupt carbon fixation rates and weaken the biological carbon pump, reducing the ocean's natural capacity to absorb CO₂. Future marine stability will depend on how effectively nanoplankton adapt to these rapid environmental shifts. To predict long-term changes in ocean carbon cycling and global climate control, we need to know their resilience.

India's Ideal Climate Adaptation Goals

- ❖ Reduce coastal pollution and nutrient runoff.
- ❖ Monitor and manage ocean acidification impacts.
- ❖ Strengthen marine ecosystem protection and restoration.
- ❖ Expand plankton monitoring and scientific research capacity.
- ❖ Integrate ocean carbon processes into national climate policies.

India's plan to adapt to climate change should include conserving nanoplankton, the microscopic sea producers that fix carbon. Better wastewater treatment and less agricultural runoffs help keep coastal waters clean, which is good for the proliferation of nanoplankton. It is also crucial to keep an eye on ocean acidification, especially for delicate populations like coccolithophores that help store carbon for a long time. Strengthening coastal ecosystems such as mangroves, estuaries and seagrass beds makes it easier for plankton-driven food webs to thrive and helps store carbon naturally. India will have a better understanding of carbon flows in the Arabian Sea and Bay of Bengal by doing more oceanographic research, satellite monitoring, and microbial studies. Finally, making sure that India's national climate policies are in line with marine carbon processes makes sure that the role of nanoplankton is well understood in the country's overall climate resilience strategy.

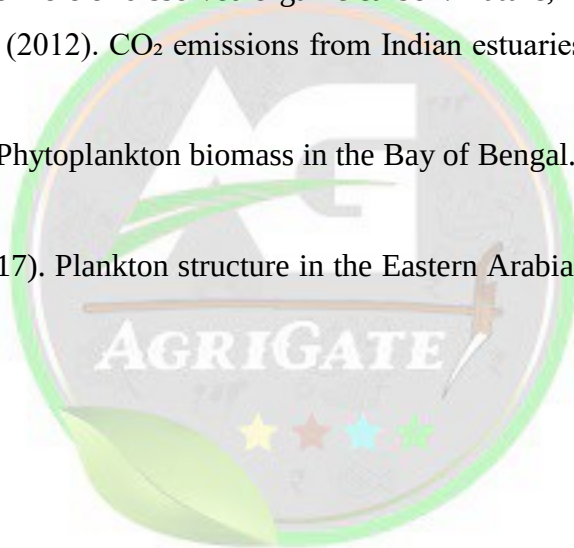
Conclusion

Nanoplankton are microscopic, but they have an enormous impact on the Earth's climate because they drive primary production and power the biological carbon pump. They are important for ocean health and long-term carbon storage because they can take CO₂ out of the air and support marine food webs. As climate change influences the temperature, chemistry, and nutrient balance of the ocean, it becomes more and more critical to know how nanoplankton responds. To protect their ecological function, we need to improve monitoring, decrease pollution along the coast, and include microbial carbon processes in national climate planning. It is important to protect nanoplankton not just to keep marine biodiversity alive, but also to keep the global carbon cycle stable. Their strength and hidden influence remind us that climatic solutions often start with small things.

References

Azam, F., & Malfatti, F. (2007). Microbial structuring of marine ecosystems. *Nature Reviews Microbiology*, 5, 782–791.

- Buitenhuis, E. T., et al. (2012). Sensitivity of marine phytoplankton biomass to environmental change. *Global Biogeochemical Cycles*, 26, GB1023.
- Poulton, A. J., et al. (2007). Phytoplankton community structure and carbon export. *Deep-Sea Research II*, 54, 1–26.
- Raven, J. A. (1998). Small is beautiful: advantages of being a small phytoplankton. *Plant, Cell & Environment*, 21, 649–654.
- Behrenfeld, M. J. (2010). Abandoning Sverdrup's critical depth hypothesis. *Ecology*, 91(4), 977–989.
- Monteiro, F. M., et al. (2016). Coccolithophore calcification and the carbon cycle. *Annual Review of Marine Science*, 8, 123–158.
- Karl, D. M. (2002). Hidden role of dissolved organic carbon. *Nature*, 419, 375–379.
- Sarma, V. V. S. S., et al. (2012). CO₂ emissions from Indian estuaries. *Marine Chemistry*, 142–144, 53–64.
- Gauns, M., et al. (2005). Phytoplankton biomass in the Bay of Bengal. *Deep-Sea Research II*, 52, 1969–1981.
- Krishna, M. S., et al. (2017). Plankton structure in the Eastern Arabian Sea. *Oceanologia*, 59(4), 414–427.



Volume: 05 Issue No: 12

GYMNOSPORIA MONTANA (ROTH) BENTH. MEDIATED GREEN SYNTHESIS OF COPPER OXIDE NANOPARTICLES: CHARACTERIZATION AND BIOLOGICAL INSIGHTS

Article ID: AG-VO5-I12-45

***Krishna Chavda, Barad Harsidhdhi and Rudrik Dave**

Master of Science in Zoology, Gujarat University, India

*Corresponding Author Email ID: krishnachavda213@gmail.com

Abstract

Nanotechnology has revolutionized material science by manipulating matter at the nanoscale, unlocking remarkable physicochemical and biological properties. Inspired by the ancient Ayurvedic practice of Bhasma preparation, this study presents a green and sustainable approach for synthesizing copper oxide nanoparticles (CuONPs) using the medicinal plant *G. montana*. The plant extract, rich in flavonoids, alkaloids, and phenolics, served as a natural reducing and stabilizing agent, enabling the formation of biocompatible CuONPs. The synthesized nanoparticles were thoroughly characterized using UV-Vis spectroscopy, FTIR, SEM-EDAX, dynamic light scattering, and zeta potential analysis, revealing irregular, clustered structures with nanoscale dimensions and high copper content. The CuONPs demonstrated potent antioxidant activity in FRAP and phosphomolybdate assays and exhibited significant photocatalytic degradation of methylene blue dye under visible light, highlighting their environmental remediation potential. This eco-friendly approach seamlessly integrates traditional herbal wisdom with modern nanoscience, offering a promising platform for biomedical applications, antioxidant therapeutics, and sustainable environmental solutions.

Keywords: *G. montana*, CuONPs, Antioxidant activity, Photocatalytic activity

1. Introduction

The study explores nanotechnology, the manipulation of materials at the 1–100 nm scale, highlighting its deep roots in Ayurveda, where Bhasma preparation produced nano-sized particles to enhance bioavailability and reduce toxicity (Patel *et al.*, 2023; Singh *et al.*, 2021). Ayurvedic texts like Ayurveda Prakasha describe copper as detoxifying and therapeutic, aligning

with the modern antimicrobial and medicinal potential of CuONPs (Sharma *et al.*, 2020; Phang *et al.*, 2021).

This research focuses on the green synthesis of CuONPs using *G. montana* extract, whose phytochemicals act as natural reducers and stabilizers (Patel *et al.*, 2023; Peddi *et al.*, 2021). The nanoparticles are characterized by UV-Vis, FTIR, SEM-EDAX, TEM, XRD, and zeta potential techniques (Phang *et al.*, 2021; Singh *et al.*, 2021). Their antioxidant activity (via DPPH, Phosphomolybdate, and PFRAP assays) and photocatalytic dye degradation demonstrate biomedical and environmental applications (Patel *et al.*, 2023; Peddi *et al.*, 2021). The study promotes eco-friendly, sustainable nanotechnology, employing both Top-Down and Bottom-Up synthesis approaches (Sharma *et al.*, 2020; Phang *et al.*, 2021).

2. Materials and Methods

Chemicals & Reagents: Purchased from HiMedia (India), Sigma-Aldrich (USA), GeNei (India). Prepared in distilled water, Millipore water, or appropriate solvents. All reagents were analytical grade.

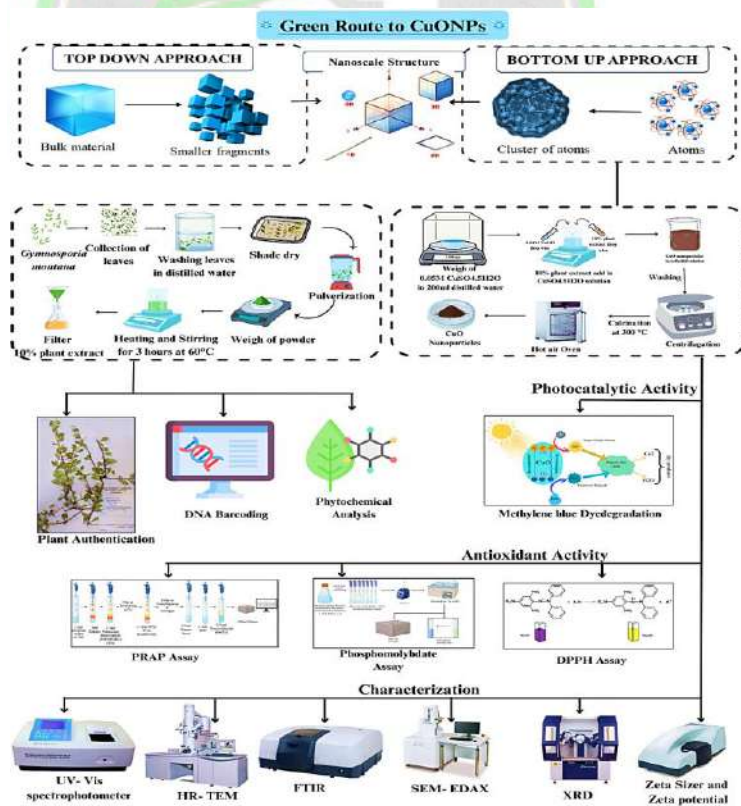


Figure 2.1: Schematic representation of synthesis of CuONPs.

For Qualitative Phytochemical Analysis: *G. montana* leaf extract, acids, bases, Fehling's solutions, Benedict reagent, aluminum chloride, alcohols, chloroform, ninhydrin, biuret reagent, and others.

For Quantitative Analysis: *G. montana* extract, acetic acid, ammonium hydroxide, aluminum chloride, potassium acetate, quercetin, gallic acid, Folin-Ciocalteu reagent, sodium carbonate, HCl, sulfuric acid, and phenol. CuONPs Synthesis: Copper sulfate pentahydrate, *G. montana* extract, NaOH, distilled water.

Antioxidant Assays (PFRAP & Phosphomolybdate): Ascorbic acid, ferric chloride, potassium ferrocyanide, ammonium molybdate, PBS buffer, CuONPs, *G. montana* extract, sulfuric acid, sodium phosphate. Glasswares are Borosilicate.

2.1 Preparation of *G. montana* Leaf Extract

2.1.1 Collection & Authentication: Leaves collected from Visavadar, Gujarat (Feb 11, 2025). Verified by Gujarat University (Authentication No.: GU/BOT//C/G 05).

2.1.2 DNA Barcoding: Leaf DNA isolated, amplified using RBCL primers, sequenced, and analyzed with NCBI BLAST for species confirmation.

2.1.3 Extract Preparation: Leaves washed, shade-dried 8–10 days, ground into powder. 10 g powder macerated in 100 mL distilled water, heated at 60°C for 3 h, filtered, and stored at 4°C.

2.2 Phytochemical Analysis

2.2.1 Qualitative: Standard tests for alkaloids, flavonoids, tannins, saponins, terpenoids, steroids, glycosides, proteins, and amino acids.

2.2.2 Quantitative Analysis:

Total Alkaloid Content (TAC): Gravimetric method with acetic acid extraction, ammonium hydroxide precipitation, oven drying, expressed as % of raw material.

Total Flavonoid Content (TFC): Aluminum chloride colorimetric method, absorbance at 415 nm, reported as mg quercetin equivalent/g.

Total Phenolic Content (TPC): Folin-Ciocalteu method, absorbance at 765 nm, reported as mg gallic acid equivalent/g.

2.3 Green Synthesis of CuONPs (CuONPs)

Principle: Phytochemicals in *G. montana* extract reduce Cu^{2+} ions to CuONPs and act as natural stabilizers. Procedure: 0.05 M $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ dissolved in 200 mL water, heated, 10%

leaf extract added dropwise with stirring. NaOH added to maintain pH 8. Colloidal solution centrifuged, washed, dried, and calcined at 300°C.

2.4 Characterization

2.4.1 UV-Visible Spectroscopy

The formation of CuONPs monitored by color change and absorbance spectrum (200-800 nm).

A characteristic peak at 300-400 nm confirmed nanoparticle synthesis.

2.4.2 Fourier Transform Infrared Spectroscopy (FTIR)

The synthesized CuONPs were separated by centrifugation (2000 rpm, 20 min), dried at 80°C, and ground into fine powder. The powder was mixed with KBr to form pellets for FTIR analysis to identify functional groups involved in the bio-reduction of Cu^{2+} and capping of nanoparticles. Spectra were recorded in the $3500 - 500 \text{ cm}^{-1}$ range using OPUS 7.5 software (Hemmati *et al.*, 2020; Imran *et al.*, 2016).

2.4.3 Zeta Potential and Particle Size Analysis

The surface charge and stability of CuONPs were measured using a Zeta Sizer Nano ZS90 at 25°C. The nanoparticle suspension was sonicated for 5 min before measurement. Zeta potential was recorded with Zeta Sizer 7.13 software to assess colloidal stability (Malvern Instruments, 2020).

2.4.4 SEM-EDAX Analysis

CuONPs morphology and elemental composition were examined using SEM coupled with EDX. Samples were mounted on aluminum stubs with conductive tape and coated with a metallic layer. SEM images were taken at various magnifications to observe particle shape, size, and surface structure. EDX confirmed the presence of copper and oxygen (Aghajari *et al.*, 2020; Imran *et al.*, 2016).

2.5 Activity Assays

2.5.1 Potassium Ferricyanide Reducing Antioxidant Power (PFRAP) Assay

The PFRAP assay measures antioxidant capacity via reduction of Fe^{3+} to Fe^{2+} by electron-donating compounds, forming Prussian blue detected at 700 nm. Extracts (50–300 µg/mL) were incubated with phosphate buffer and potassium ferricyanide at 50°C for 30 min. After addition of TCA and centrifugation, the supernatant was mixed with FeCl_3 and

absorbance measured. Ascorbic acid served as the standard (Benzie & Strain, 1996; Oyaizu, 1986).

2.5.2 Phosphomolybdate Assay

This assay forms a phosphomolybdate complex in acidic conditions that produces a blue-colored compound proportional to phosphate content. Test samples were reacted with salicylic acid, sodium phosphate, ammonium molybdate, and sulfuric acid, incubated, and absorbance measured at 695 nm. % inhibition was calculated using the formula: % Inhibition = $((A_0 - A_1)/A_0) \times 100$, where A_0 and A_1 are control and sample absorbance, respectively (Fiske & Subbarow, 1925).

2.5.3 Photocatalytic Degradation of Methylene Blue (MB)

CuONPs degrade MB dye under light via generation of electron-hole pairs forming reactive radicals, which break down the dye. A 1 mg/mL MB solution and 1 mg/mL CuONPs suspension were mixed in a transparent container and exposed to light. Samples were withdrawn every 10 min, and MB concentration monitored using UV-visible spectrophotometry. Degradation efficiency (%) was calculated as: % Degradation = $((C_0 - C_t)/C_0) \times 100$, where C_0 = initial and C_t = dye concentration at time t.

3. Results

3.1 Collection and Authentication of *G. montana*

Leaves of *G. montana* were collected from Visavadar, Gujarat, India. The species was authenticated using:

3.2 Molecular Technique (DNA Barcoding): rbcL gene sequencing confirmed high nucleotide homology with *Gymnosporia senegalensis*, supporting precise species identification through phylogenetic analysis.

Both forward and reverse primers amplified 552 bp of the rbcL gene. BLAST analysis showed 100% identity with *Gymnosporia senegalensis* (voucher RBN294), confirming species-level identification. Evolutionary divergence and phylogenetic analysis were performed using the Maximum Composite Likelihood model, involving 11 nucleotide sequences and 475 positions in the final dataset.

3.3 Plant Extraction:

Aqueous extract of *G. montana* leaves was prepared using maceration, yielding 14.68%.

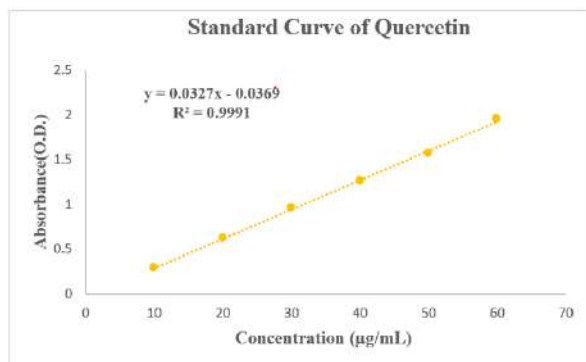
3.4 Phytochemical Screening:

3.4.1 Qualitative: Presence of alkaloids, flavonoids, carbohydrates, tannins, steroids, saponins, terpenoids, and glycosides; proteins and amino acids were absent.

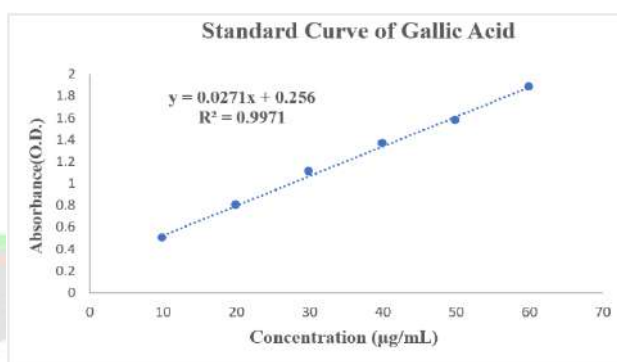
3.4.2 Quantitative: Total Alkaloid Content (TAC): 11.2 mg/100 g leaf powder.

Total Flavonoid Content (TFC): 21.17 mg QE/g extract.

Total Phenolic Content (TPC): 12.23 mg GAE/g extract.



Graph 3.4.2: Calibration Curve of standard quercetin for TFCs. TPCs

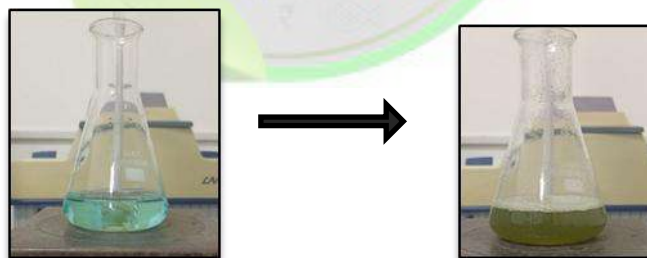


Graph 5.4.3: Calibration Curve of standard gallic acid for

3.5 Characterization of CuONPs Synthesized Using *G. montana*

3.5.1 Visual Observation

Formation of CuONPs was indicated by a color change from bright blue → greenish-blue → dark brown/black. This reflects nucleation and growth of CuONPs due to electronic



transitions and quantum confinement effects.

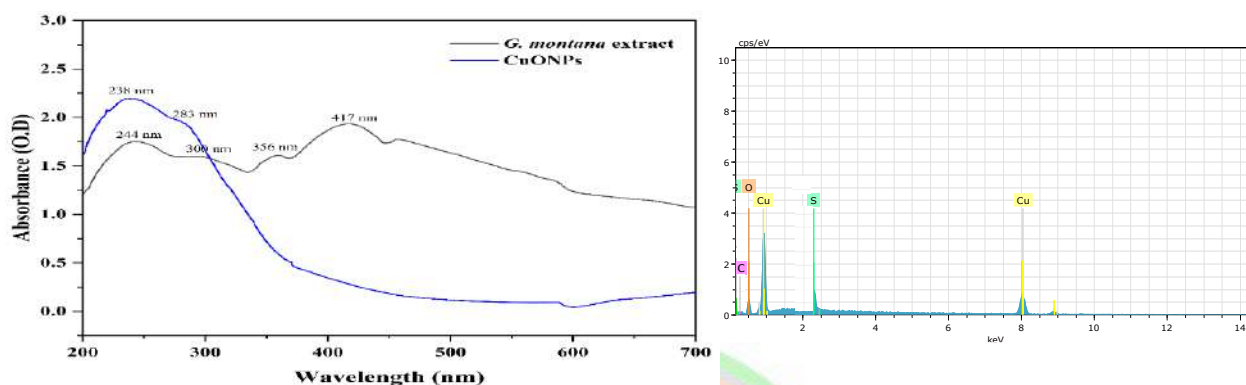
Figure 3.5.1: Synthesized of CuONPs by *G. montana*. [A] Before synthesis and [B] After synthesis

3.5.2. UV-Vis Spectroscopy:

Absorption peak observed at 250–350 nm, characteristic of CuONPs, confirming successful synthesis.

5.5.3. EDAX Analysis:

Elemental composition of CuONPs includes Copper (Cu), Oxygen (O), Carbon (C), and Sulfur (S). Cu: 60.08 wt%, 24.16 at%; O: 29.44 wt%, 62.63 at%; C: 6.07 wt%, 9.70 at%; S: 4.41 wt%, 3.51 at%. The results confirm the major presence of copper oxide, with minor



contributions from carbon and sulfur, possibly from residual organic material or synthesis precursors.

Graph 5.5.2.1: Absorption spectra of *G. montana* and synthesized CuONPs.

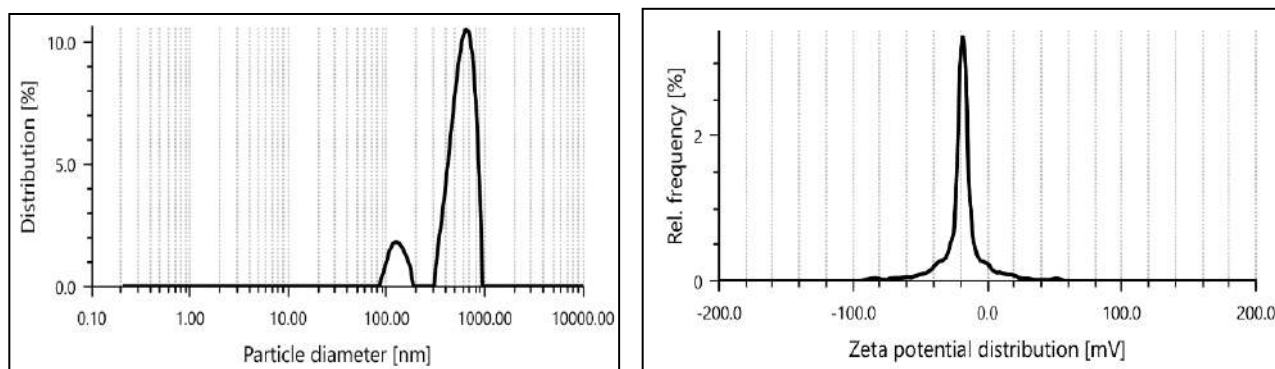
Graph

5.5.3.1: EDAX spectrograph of CuONPs.

5.5.4. Particle Size and Zeta Potential (DLS/Zeta Sizer):

Average particle size: 823.2 nm (hydrodynamic diameter, likely due to aggregation in solution).

Polydispersity index (PDI): 31.2%, Zeta potential: negative, indicating moderate stability and anionic surface charge.



Graph 5.5.4.1: Zeta Size of *G. montana* synthesized CuONPs.

5.5.5. SEM Analysis:

Particles exhibited irregular, rough, clustered morphology with hierarchical arrangement. Primary particle sizes ranged 0-60 nm, with the majority between 20–30 nm (mean ~ 22.4 nm, SD ~ 9.1 nm). Surface roughness and cavities suggest successful formation of 3D nanoscale structures.

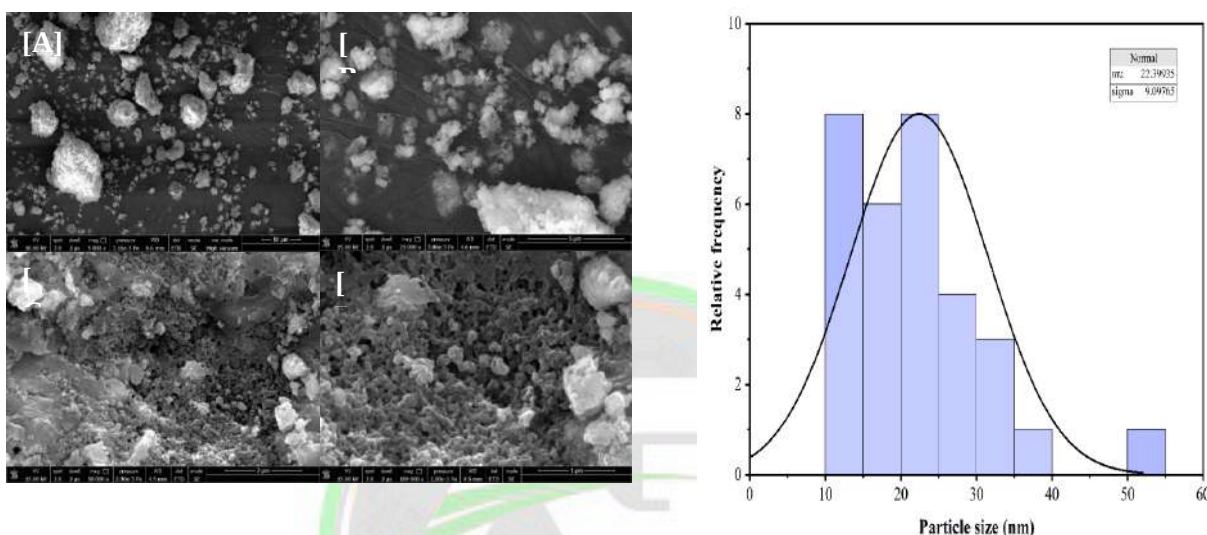
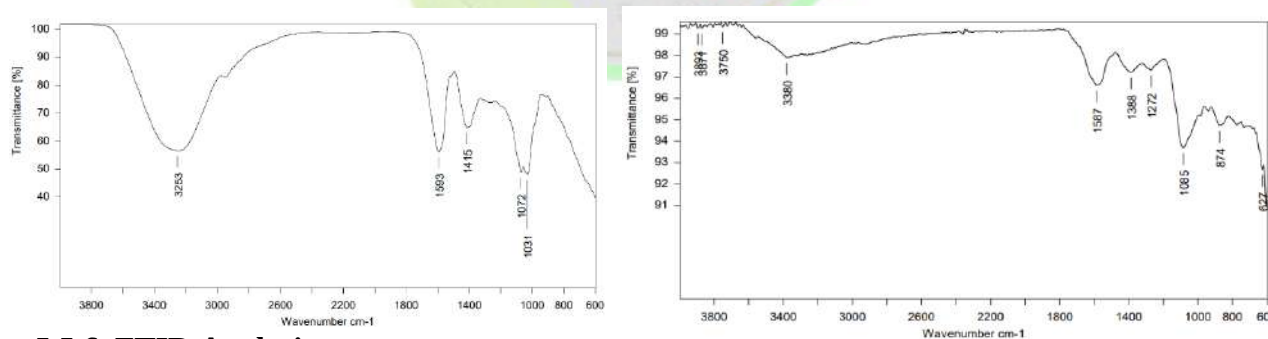


Figure 5.5.5.1: SEM Analysis of CuONPs at different resolution [A] to [D] of

10 μm , 5 μm , 2 μm , 1 μm .

Graph 5.5.5.1:

Particle size distribution of CuONPs.



5.5.6. FTIR Analysis:

Graph 5.5.6.1: FTIR Spectra of *G. montana* extract.

Graph 5.5.6.2: FTIR Spectra of CuONPs.

G. montana extract: peaks for OH (3252 cm^{-1}), C=O (1593 cm^{-1}), C-H (1415 cm^{-1}), and C-O (1072 & 1030 cm^{-1}), indicating phytochemicals responsible for reduction and capping

Synthesized CuONPs: Cu-O stretching at 627 cm^{-1} and O-H peaks (residual capping), confirming nanoparticle formation.

5.6 Antioxidant Activity:

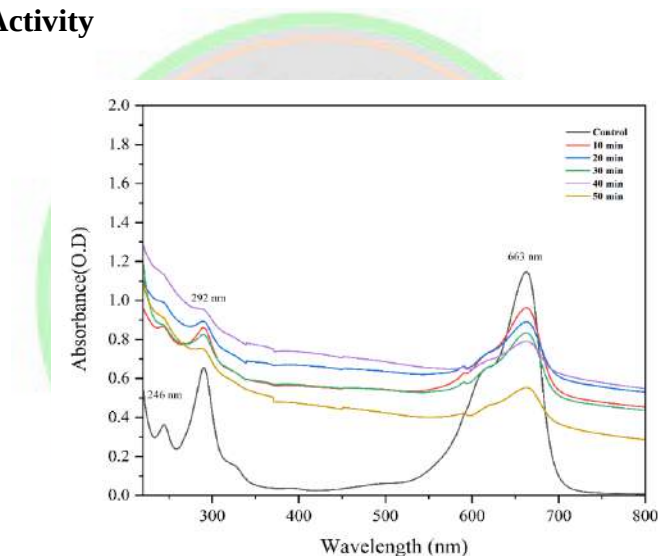
5.6.1 FRAP Assay

CuONPs exhibited 41.09% scavenging, higher than *G. montana* extract (20.11%), with Ascorbic Acid as standard showing 118.39%.

5.6.2 Phosphomolybdate Assay (Total Antioxidant Capacity)

***G. montana* extract:** 596.67 μg AAE/g, **CuONPs:** 616.57 μg AAE/g, CuONPs show enhanced antioxidant potential, likely due to surface-bound phytochemicals and nanoscale effects.

5.7 Photocatalytic Activity



Graph 5.7.1: UV–visible absorption spectrum of methylene blue in the presence of CuONP at various time intervals.

Degradation of methylene blue dye under visible light reached ~51.76% in 50 minutes. Rapid degradation during the first 40 minutes suggests efficient generation of reactive species. Indicates moderate photocatalytic potential for environmental remediation and wastewater treatment applications.

Conclusion

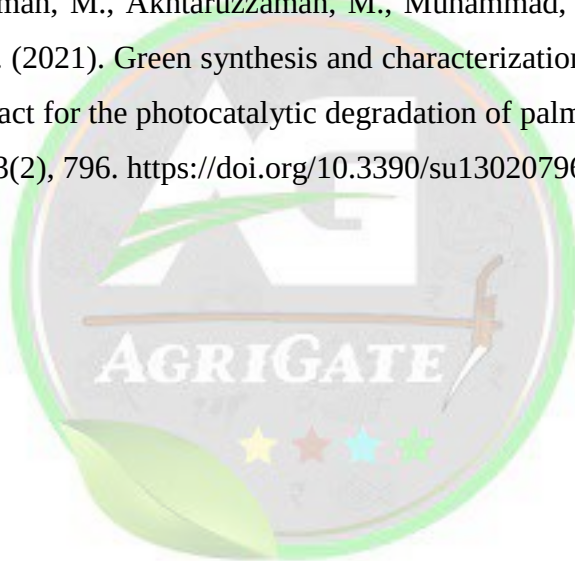
This study demonstrates that *G. montana* can be used as an eco-friendly, sustainable source for synthesizing copper oxide nanoparticles (CuONPs), leveraging its rich phytochemical content to act as natural reducing and stabilizing agents. The synthesized CuONPs were well characterized, showing nanoscale size, irregular morphology, and high

copper content, and exhibited strong antioxidant activity as well as notable photocatalytic dye-degradation capability. These findings highlight the potential of *G. montana* derived CuONPs for applications in healthcare, environmental remediation, and sustainable nanotechnology. Future research should focus on optimizing synthesis, assessing biocompatibility, testing against drug-resistant pathogens, and scaling up the process for broader applications.

References

- Patel, K. N., Trivedi, P., Thakar, M. K., & Sindhav, G. M. (2023). Gold nanoparticles synthesis using *G. montana* L. and its biological profile: a pioneer report. *Journal of Genetic Engineering and Biotechnology*, 21(1), 1–10. <https://doi.org/10.1186/s43141-023-00525-6>
- Singh, R., Shukla, S., & Choudhary, S. (2021). Phytochemical-mediated green synthesis of CuONPs and their biomedical applications. *Journal of Nanobiotechnology*, 19(1), 1-12. <https://doi.org/10.1186/s12951-021-00932-4>
- Sharma, P., Kumar, R., & Joshi, S. (2020). Green synthesis of metal nanoparticles using plant extracts: An overview. *Journal of Environmental Chemical Engineering*, 8(5), 104039. <https://doi.org/10.1016/j.jece.2020.104039>
- Peddi, P., Ptsrk, P. R., Usha Rani, N., & Lakshmi Tulasi, S. (2021). Green synthesis, characterization, antioxidant, antibacterial, and photocatalytic activity of Suaeda maritima (L.) Dumort aqueous extract-mediated copper oxide nanoparticles. *Journal of Genetic Engineering and Biotechnology*, 19(1), 131. <https://doi.org/10.1186/s43141-021-00229-9>
- Benzie, I. F., & Strain, J. J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of “antioxidant power”: The FRAP assay. *Analytical Biochemistry*, 239(1), 70–76. <https://doi.org/10.1006/abio.1996.0292>
- Fiske, C. H., & Subbarow, Y. (1925). The colorimetric determination of phosphorus. *Journal of Biological Chemistry*, 66(2), 375–400.
- Hemmati, S., Ghaedi, M., & Hosseini, M. (2020). Characterization of copper oxide nanoparticles synthesized using plant extract and their photocatalytic applications. *Materials Science in Semiconductor Processing*, 107, 104807. <https://doi.org/10.1016/j.mssp.2020.104807>

- Imran, M., Rauf, A., Ahmad, N., & Aslam, M. (2016). Green synthesis of copper oxide nanoparticles using plant extracts and their applications: A review. *Journal of Molecular Structure*, 1127, 783–790. <https://doi.org/10.1016/j.molstruc.2016.08.042>
- Malvern Instruments. (2020). Zetasizer Nano Series user manual (7th ed.). Malvern Panalytical.
- Oyaizu, M. (1986). Studies on products of browning reaction: Antioxidant activities of products of browning reaction prepared from glucosamine. *Japanese Journal of Nutrition*, 44(6), 307–315. <https://doi.org/10.5264/eiyogakuzashi.44.307>
- Aghajari, N., Hosseini, S. S., & Khosravi, A. (2020). Green synthesis and characterization of copper oxide nanoparticles using plant extracts. *Journal of Nanostructure in Chemistry*, 10(1), 1–12. <https://doi.org/10.1007/s40097-020-00330-0>
- Phang, Y.-K., Aminuzzaman, M., Akhtaruzzaman, M., Muhammad, G., Ogawa, S., Watanabe, A., & Tey, L.-H. (2021). Green synthesis and characterization of CuONPs derived from Papaya peel extract for the photocatalytic degradation of palm oil mill effluent (POME). *Sustainability*, 13(2), 796. <https://doi.org/10.3390/su13020796>



Volume: 05 Issue No: 12

SMART AQUACULTURE: INTEGRATING IOT, AI, AND COMPUTER VISION FOR OPTIMIZED FISH FARMING

Article ID: AG-VO5-I12-46**Dona Merli A R***

Department of Aquaculture, Dr. M.G.R. Fisheries College and Research Institute, Ponneri,
Tiruvallur - 601 204, Tamil Nadu, India

Corresponding Author EMail ID: donamerli2004@gmail.com

Abstract

Smart aquaculture, also known as precision aquaculture, is transforming traditional fish farming by integrating Internet of Things (IoT) devices, computer vision, and artificial intelligence (AI) to optimize fish growth, feeding efficiency, and environmental sustainability. Recent advancements in machine learning and IoT technologies have enabled automated monitoring and decision-making, significantly improved productivity and reducing operational costs. This article reviews current technologies in smart aquaculture, discusses their applications in fish feeding, water-quality management, and behavior monitoring, and explores challenges and future research directions.

Keywords: Smart aquaculture, Internet of Things, Artificial Intelligence, Computer Vision, Enhanced food safety and environmental sustainability.

Introduction

Aquaculture plays a crucial role in global food security, providing nearly 50% of consumed fish worldwide. Traditional aquaculture practices are often labor-intensive, relying on manual feeding schedules and routine water-quality assessments. However, these methods are prone to inefficiency, leading to overfeeding, wasted resources, and environmental pollution. The advent of **smart aquaculture** offers solutions by leveraging IoT sensors, machine learning algorithms, and computer vision systems to create automated, real-time, data-driven management approaches (Hossam et al., 2024; O'donncha & Grant, 2019).

Precision aquaculture is characterized by the integration of multiple technologies: IoT devices for continuous environmental monitoring, AI and deep learning models for predictive analysis, and computer vision for fish behavior and biomass assessment. Together, these technologies allow for optimized feeding, efficient water-quality management, and enhanced monitoring of fish health and welfare (Vettom et al., 2024; Zhang et al., 2020). This approach not only improves productivity but also promotes sustainability by minimizing overfeeding and reducing chemical and nutrient discharge into surrounding ecosystems.

IoT in Smart Aquaculture

The **Internet of Things (IoT)** serves as the backbone of modern smart aquaculture systems. Sensors deployed in ponds and tanks continuously monitor water quality parameters such as temperature, pH, dissolved oxygen, and turbidity. These sensors communicate data in real-time to cloud platforms or edge devices, allowing farmers to track pond conditions remotely (Mohd Jais et al., 2024; Eso et al., 2024). Advanced systems, such as the *AquaBot*, integrate robotics to sample water automatically, analyze data using machine learning algorithms, and recommend optimal fish species for specific water conditions (Hemal et al., 2024).

IoT-based monitoring ensures environmental conditions remain within optimal ranges, directly affecting fish growth, feed conversion ratios, and overall farm productivity. Additionally, low-cost IoT solutions have been developed to make smart aquaculture accessible to small-scale farmers, demonstrating the feasibility of precision aquaculture in resource-limited settings (Mohd Jais et al., 2024).

Computer Vision and Machine Learning Applications

A major cost and waste factor in aquaculture is feeding. Feeding often constitutes a significant portion of production costs, and inefficient feeding leads to wasted feed, poor water quality, and suboptimal growth. Researchers have developed computer vision and AI-based systems to detect and count fish, estimate fish size and biomass, and dynamically compute feeding amounts based on actual biomass, fish count, and environmental conditions. The 2024 study by Hossam, Heakl, and Gomaa demonstrates a real-time IoT sensor setup combined with a dual-camera vision system that applies object detection and keypoint detection models to estimate fish weight and compute optimal feed amounts. The system achieved high precision in keypoint detection and fish counting, with simulations suggesting that optimized feeding could significantly increase production compared to traditional farms. Broader reviews indicate that

machine vision is increasingly used for size and biomass estimation, species identification, disease detection, behavior analysis, and feeding decision-making. Computer vision and machine learning are increasingly used to monitor fish behavior, estimate biomass, and control feeding schedules. Vision-based systems track fish movement, count individuals, and detect stress or abnormal behavior. Automated feeding systems rely on real-time fish activity analysis to deliver feed proportionally, preventing overfeeding and reducing waste (Hossam et al., 2024; Patro et al., 2023).

Deep learning algorithms, such as convolutional neural networks (CNNs), allow the extraction of complex features from underwater images and videos, enabling accurate detection of fish size, health status, and swimming patterns (Yang et al., 2020). Integrating AI with IoT enhances system intelligence: data from sensors and vision systems feed into predictive models that optimize feeding rates, detect early signs of disease, and suggest corrective actions (Roy et al., 2024). Deep learning can handle complex data to enable live-fish identification, size estimation, behavior monitoring, water quality prediction, and feeding control, though challenges include the need for large labeled datasets and significant computational resources. Computer vision and AI enable precise, fish-level feeding control, which is essential for sustainable and efficient aquaculture.

Feeding Optimization in Precision Aquaculture

Feeding represents one of the highest costs in aquaculture operations. Traditional static feeding schedules often result in inefficiencies. Machine vision and AI-based feeding systems dynamically adjust feed delivery based on fish activity and biomass estimations, improving feed conversion ratios and reducing environmental pollution (Hossam et al., 2024; Zhang et al., 2020). Intelligent feeding systems have demonstrated increased growth rates and decreased feed wastage, highlighting the economic and environmental advantages of precision feeding.

Recent studies have implemented computer vision to monitor tilapia and shrimp, delivering feed adaptively according to real-time analysis of swimming and foraging behaviors (Montaño Blacio et al., 2025). These methods are supported by IoT-enabled actuators that dispense feed automatically, further streamlining farm operations.

Water Quality Monitoring and Environmental Control

Maintaining optimal water quality is critical for fish health and growth. Smart aquaculture systems employ IoT sensors combined with AI models to continuously monitor and

manage water parameters. Fuzzy logic, rule-based systems, and machine learning algorithms can trigger aerators, water pumps, or chemical dosing to maintain ideal conditions (Amaliah et al., 2024; Capetillo-Contreras et al., 2024). Such automated environmental control ensures consistent fish welfare, reduces stress-related mortality, and increases overall productivity.

Additionally, IoT-enabled monitoring enables predictive maintenance, allowing farmers to preemptively address water quality issues before they affect fish performance (Hemal et al., 2024). These integrated systems can also record historical data to support long-term farm management decisions, enhancing sustainability.

Behavioral and Welfare Monitoring

Monitoring fish behavior is an emerging area in smart aquaculture. Changes in swimming patterns, aggregation behavior, or activity levels can indicate stress, disease, or suboptimal feeding. Computer vision systems combined with AI can detect such changes in real-time, alerting farmers to intervene promptly (Patro et al., 2023; Folkman et al., 2025). Welfare monitoring contributes to both ethical aquaculture practices and improved productivity by reducing mortality rates and promoting optimal growth.

Challenges and Future Directions

Despite advances, smart aquaculture faces several challenges. High initial investment costs, infrastructure requirements, and the need for reliable internet connectivity limit adoption in developing regions. Data scarcity and variability in environmental conditions present challenges for AI model training and generalization (Yang et al., 2020; Huang & Khabusi, 2025). Moreover, integrating diverse technologies into a cohesive, maintainable system requires cross-disciplinary expertise.

Future research should focus on low-cost, scalable solutions suitable for small and medium-sized farms, robust AI models that can handle diverse environmental conditions, and the integration of multi-modal sensing technologies. The concept of “Fish Farming 5.0” envisions fully automated, data-driven aquaculture systems that optimize every aspect of fish production, from environmental monitoring to feed delivery and disease detection (Roy et al., 2024).

Conclusion

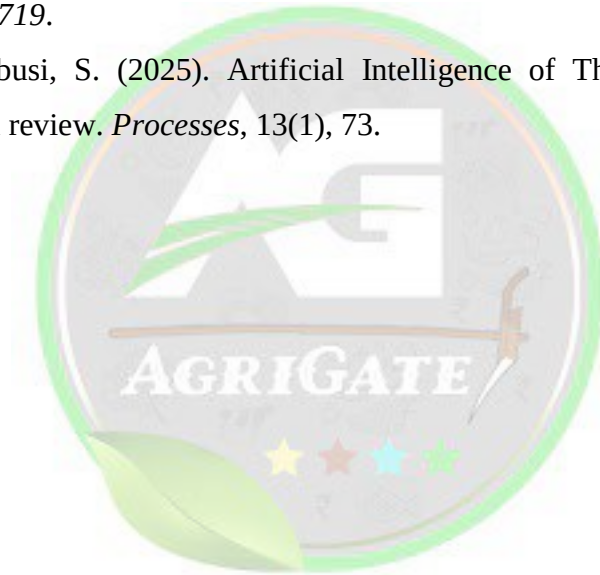
Smart aquaculture represents a paradigm shift in fish farming, offering automation, real-time monitoring, and data-driven decision-making. By combining IoT, computer vision, and AI, precision aquaculture systems optimize feeding, maintain water quality, monitor fish behavior,

and ultimately improve productivity and sustainability. While challenges remain, ongoing research demonstrates the potential for widespread adoption of these technologies, paving the way for efficient, sustainable, and environmentally responsible aquaculture practices. . Successfully implemented, smart aquaculture can meet global seafood demand while reducing environmental impact and enhancing food security.

References

- Hossam, R., Heakl, A., & Gomaa, W. (2024). Precision aquaculture: An integrated computer vision and IoT approach for optimized tilapia feeding. *arXiv preprint arXiv:2409.08695*.
- O'donncha, F., & Grant, J. (2019). Precision aquaculture. *IEEE Internet of Things Magazine*, 2(4), 26–30.
- Vettom, E. J., Danve, A., & Khalasi, Y. (2024). Precision Aquaculture: Integrating Technology for Enhanced Production and Sustainability. *Agric. Mag*, 3, 203–211.
- Zhang, Y., Lu, R., Qin, C., & Nie, G. (2020). Precision nutritional regulation and aquaculture. *Aquaculture Reports*, 18, 100496.
- Hemal, M. M., Rahman, A., Nurjahan, Islam, F., Ahmed, S., Kaiser, M. S., & Ahmed, M. R. (2024). An integrated smart pond water quality monitoring and fish farming recommendation AquaBot system. *Sensors*, 24(11), 3682.
- Mohd Jais, N. A., Abdullah, A. F., Kassim, M. S. M., et al. (2024). Improved accuracy in IoT-based water quality monitoring for aquaculture tanks using low-cost sensors: Asian seabass fish farming. *Heliyon*, 10(8): e29022.
- Patro, K. S. K., Yadav, V. K., Bharti, V. S., et al. (2023). IoT and ML approach for ornamental fish behaviour analysis. *Scientific Reports*, 13, 21415.
- Amaliah, A., et al. (2024). Advancing aquaculture: fuzzy logic-based water quality monitoring and maintenance system for precision aquaculture. *Aquaculture International*.
- Capetillo-Contreras, O., Pérez-Reynoso, F. D., Zamora-Antuñano, M. A., Álvarez-Alvarado, J. M., & Rodríguez-Reséndiz, J. (2024). Artificial intelligence-based aquaculture system for optimizing the quality of water: A systematic analysis. *Journal of Marine Science and Engineering*, 12(1), 161.

- Montaño Blacio, M., Borbor, R., Gómez, Ó., et al. (2025). The IoT revolution in aquaculture: Technological advances in automated feeding and water quality monitoring in shrimp ponds. *Journal of Applied Research and Technology*, 23(3), 266–274.
- Yang, J., Zhang, D., & Li, X. (2020). Deep learning for smart fish farming: applications, opportunities and challenges. *arXiv preprint arXiv:2004.11848*.
- Roy, D., Padhiary, M., & Roy, P., Barbhuiya, J. A. (2024). Artificial intelligence-driven smart aquaculture: revolutionizing sustainability through automation and machine learning. *LatIA Journal*.
- Folkman, L., Vo, Q. L. K., Johnston, C., Stantic, B., & Pitt, K. A. (2025). A computer vision method to estimate ventilation rate of Atlantic salmon in sea fish farms. *arXiv preprint arXiv:2504.19719*.
- Huang, Y.-P., & Khabusi, S. (2025). Artificial Intelligence of Things (AIoT) advances in aquaculture: A review. *Processes*, 13(1), 73.



Volume: 05 Issue No: 12

ANTIBIOTIC STEWARDSHIP PROGRAMS: A CORNERSTONE FOR RESPONSIBLE ANTIMICROBIAL USE

Article ID: AG-VO5-I12-47**K Kannan***

Assistant Professor, Department of Veterinary Pharmacology and Toxicology, Veterinary College and Research Institute, Orathanadu, Thanjavur-614625, Tamil Nadu

*Corresponding Author Email ID: dr.kannan09@gmail.com

Abstract

Antibiotic Stewardship Programs (ASPs) have become indispensable for ensuring rational antimicrobial use in human and veterinary medicine. With antimicrobial resistance (AMR) rising rapidly, stewardship interventions provide a structured and science-driven approach to optimize therapy, reduce misuse, and safeguard antibiotic efficacy.

Introduction

Antibiotics revolutionized healthcare by transforming fatal infections into manageable conditions. However, decades of indiscriminate use, over-prescription, subtherapeutic dosing, and blanket use in livestock have accelerated antimicrobial resistance (AMR). To combat this growing threat, Antibiotic Stewardship Programs (ASPs) emerged as institutional and national strategies to:

- Optimize antibiotic use
- Prevent AMR
- Improve therapeutic outcomes
- Reduce economic burden
- Promote One Health safety

The veterinary sector plays a critical role due to the interconnectedness of animals, humans, and the environment.

Core Principles of Antibiotic Stewardship

The Five Rs of Antibiotic Stewardship

1. Right Drug

2. Right Dose
3. Right Duration
4. Right Route
5. Right Diagnosis

Each step is essential to ensure optimal therapy with minimal AMR selection pressure.

Essential Components of an Effective ASP

Table 1. Core Components of Antibiotic Stewardship Programs

Component	Description	Examples in Veterinary Setting
Leadership Commitment	Institutional support, resources	Dedicated ASP team, farm-level policies
Accountability	Responsibility assigned to a leader	Veterinary pharmacologist heading ASP
Drug Expertise	Access to infectious disease experts	Microbiologist support, lab tie-ups
Action Strategies	Interventions to optimize use	De-escalation, prior approval
Tracking	Monitoring use & resistance	AMU logs, antibiograms
Reporting	Regular feedback	Monthly or quarterly audits
Education	Training programs	Workshops for vets & farmers

Action-Oriented Stewardship Strategies

1. Diagnostic Stewardship

Proper diagnosis reduces empirical and unnecessary antibiotic use.

- Culture & sensitivity testing
- Use of rapid tests (PCR panels, antigen tests)
- Farm-specific antibiograms
- Pathogen mapping (seasonal & geographic trends)

2. Therapeutic Stewardship

Key practices include:

- **De-escalation** based on culture results
- **PK/PD-guided dosing** (e.g., $T > MIC$ for β -lactams, C_{max}/MIC for aminoglycosides)

- **Time-bound treatment** with 48–72-hour reassessment
- Avoiding **last-resort antibiotics** unless absolutely required
- Adherence to **withdrawal periods**

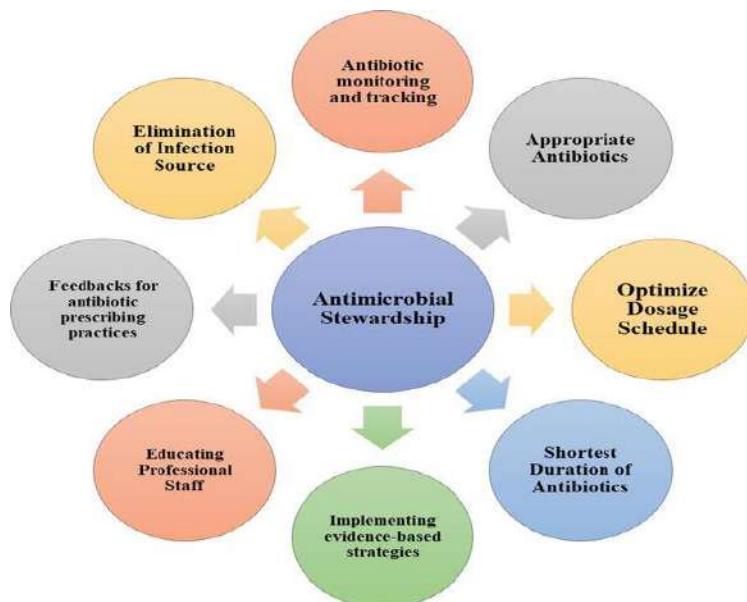


Table 2. Examples of Stewardship-Based Therapeutic Choices

Condition	Recommended Approach	Stewardship Impact
Mastitis in cattle	Narrow-spectrum after C/S	Prevents unnecessary broad-spectrum use
Respiratory disease	Empirical + 72h review	Enables de-escalation
Enteric infections	Avoid routine fluoroquinolones	Reduces resistance emergence
Post-operative care	Avoid prophylaxis beyond 24h	Decreases unnecessary exposure

Preventive Approaches in Veterinary ASP

Prevention reduces the need for antibiotic use altogether by vaccination, biosecurity measures, nutrition & management, good housing and Hygiene practices

Alternatives to Antibiotics

To reduce antibiotic pressure in animals, several safer alternatives are available:

- **Probiotics & prebiotics**
- **Phytochemicals & essential oils** (oregano, garlic, neem extracts)
- **Nanomedicine-based modulators**

- **Vaccines & immunostimulants**
- **Bacteriophages**

These options help reduce AMU without compromising productivity.

Importance of Antibiotic Stewardship Programs

1. Reducing AMR

Stewardship programs slow down the emergence of resistant bacteria such as MRSA, ESBL, and CRE in both humans and livestock.

2. Improving Clinical Success

Right drug and dose ensure faster recovery, fewer complications, and reduced relapse.

3. Economic Benefits

- Lowers drug expenditure
- Reduces mortality and productivity losses
- Minimizes hospital or treatment costs

4. Protecting One Health

Animals → Environment → Humans

Stewardship reduces cross-species spread of resistant pathogens and residues in food chains.

Challenges in Implementing ASP in Veterinary Sector

- Limited diagnostics in rural areas
- Farmer demand for “quick fix” antibiotics
- OTC availability of antimicrobials
- Lack of trained manpower
- Inadequate surveillance systems
- Resistance data often fragmented or unavailable

Future Directions

Table 3. Emerging Trends in Veterinary ASP

Domain	Future Solution	Benefit
Technology	Mobile apps for AMU tracking	Real-time data
Diagnostics	Pen-side PCR kits	Quick decision-making
Big Data & AI	AMR pattern prediction tools	Optimized drug selection

Policy	Prescription-only antibiotic laws	Prevent misuse
Research	Novel antimicrobials, nanotherapies	Reduce dependency on traditional antibiotics

Conclusion

Antibiotic Stewardship Programs are essential to safeguard the efficacy of antimicrobials, ensure animal health, protect economic interests, and uphold One Health principles. By integrating diagnostics, evidence-based therapy, farm-level protocols, and preventive strategies, stewardship programs can significantly reduce AMR while improving clinical outcomes. Veterinary professionals, farmers, and policymakers must work collectively to implement robust and sustainable ASPs across all levels of animal agriculture and clinical practice.

References

- Srinivasan A. Antibiotic stewardship: Why we must, how we can. *Cleve Clin J Med*. 2017 Sep;84(9):673-679.
- Di Bella S, Beović B, Fabbiani M, Valentini M, Luzzati R. Antimicrobial Stewardship: From Bedside to Theory. Thirteen Examples of Old and More Recent Strategies from Everyday Clinical Practice. *Antibiotics (Basel)*. 2020 Jul 10;9(7):398.
- Cosgrove SE, Srinivasan A. Antibiotic Stewardship: A Decade of Progress. *Infect Dis Clin North Am*. 2023 Dec;37(4):659-667
- Ha DR, Haste NM, Gluckstein DP. The Role of Antibiotic Stewardship in Promoting Appropriate Antibiotic Use. *Am J Lifestyle Med*. 2017 Apr 4;13(4):376-383
- Ventola CL. The antibiotic resistance crisis: part 2: management strategies and new agents. *P T*. 2015 May;40(5):344-52.

CARBON MARKETS AND CLIMATE ACTION: INDIA'S LEAP TOWARD A GREENER FUTURE

Article ID: AG-VO5-I12-48***Chandani Dave¹, Priyanka Arya¹, Ayushi Bharadwaj¹ and Manisha Verma¹**¹ICAR-Central Institute of Fisheries Education, Mumbai, India

*Corresponding Author Email ID: davechandani2000@gmail.com

Abstract

Climate change, driven largely by human activities such as burning fossil fuels, has intensified global warming and accelerated greenhouse gas accumulation in the atmosphere. International efforts to address this crisis began with the Kyoto Protocol, which required developed countries to cut emissions and introduced market-based mechanisms like emission trading, Joint Implementation and the Clean Development Mechanism. Over time, global climate governance evolved, leading to more inclusive systems like the Paris Agreement, where all nations set their own climate commitments. India, initially a major participant in CDM, gradually shifted toward domestic reforms to meet its rising development and climate goals. With policy experience from the Perform, Achieve and Trade (PAT) scheme, India developed a unified national carbon-market framework. The launch of the Carbon Credit Trading Scheme (CCTS) in 2024 represents a key milestone, combining economic growth, energy transition and climate responsibility. It also opens new opportunities for industries, farmers and communities to earn through carbon credits.

Key Words: Kyoto Protocol, Paris Agreement, Carbon Credit Trading Scheme, New Income Source for Farmers

Introduction

A change of climate which attributed directly or indirectly to human activity that alters the composition of global atmosphere, and which is in addition to natural climate variability observed over comparable time periods (UNFCCC). Before 1800s this change was led by solar activities and volcanic eruption. However, in the modern era, human activities particularly the

burning of fossil fuels for energy, transport and industrial development have become the primary drivers.

Burning fuels releases greenhouse gases (GHGs) that accumulate in the atmosphere, forming a heat-trapping layer. This trapped heat raises Earth's temperature, a phenomenon widely known as the greenhouse effect. According to scientific estimates, global temperatures may reach the critical 1.5°C warming threshold between 2030 and 2052, while an additional 0.5°C rise could still be avoided if drastic emission cuts are made within the next decade (IPCC, 2018).

Carbon dioxide is the most significant greenhouse gas contributing to this effect. Since the Industrial Revolution, its levels have sharply risen due to human activity (Dilmore and Zhang, 2017). In response, nations have developed global and national strategies to combat climate change, among which the Kyoto Protocol (2005) is a major milestone. Under this treaty, developed countries committed to legally binding emission-reduction targets, while developing nations were given flexibility to pursue growth.

UNFCCC Party Classifications

Parties under the UNFCCC are grouped as:

- Annex I: Industrialized countries and economies in transition (43 Parties including the EU). They carry legally binding emission-reduction commitments.
- Annex II: These Parties must provide financial and technical support to developing nations.
- Non-Annex I: Mostly developing countries, which may voluntarily adopt commitments as they advance economically.

Each Annex I Party is allocated a maximum allowable emission quota, or an Assigned Amount, for the commitment period. These countries can meet their targets through domestic measures, sustainable development policies and by enhancing carbon sinks such as forests under the LULUCF sector.

Kyoto Protocol Mechanisms

The Protocol introduced three market-based mechanisms designed to reduce emissions at the lowest economic cost:

1. Emission Trading / Carbon Trading

Emission trading involves buying and selling the right to emit carbon, not the emissions themselves.

Cap-and-Trade System:

A cap is fixed on total emissions, and companies receive allowances—either through auctions or free allocations (grandfathering). Countries with Quantified Emission Limitation and Reduction Commitments (QELRCs) must stay within their caps. If they emit less, they can sell excess Assigned Amount Units (AAUs); if they emit more, they must buy allowances.

Baseline-and-Credit System:

Companies do not receive allowances but are given a baseline. Emission reductions below this baseline generate tradable credits.

This mechanism allows developing countries to participate even without national caps.

Joint Implementation (JI)

Developed countries may invest in emission-reduction projects in other Annex I countries (mostly Eastern Europe) and earn credits when emissions decrease in the host country.

Clean Development Mechanism (CDM)

This mechanism allows developed countries to invest in sustainable development projects in developing nations and earn Certified Emission Reductions (CERs). CDM is supervised by an Executive Board under the Kyoto framework.

Evolution of Global Climate Policy

The Kyoto Protocol marked the world's first attempt to legally bind countries to emission-reduction targets. But over time, it became clear that Kyoto's structure—where only developed countries had binding targets—was not enough to slow global emissions. This led to a major shift in global climate governance.

1. The Rise of the Paris Agreement (2015): A Universal Approach

Unlike Kyoto, the Paris Agreement brought all countries—developed and developing—under a common framework, where each nation submits its own climate targets, known as Nationally Determined Contributions (NDCs).

Key shifts included:

- Moving from top-down targets to self-determined national pledges
- Emphasis on long-term low-carbon development pathways
- Introduction of Article 6, creating a new generation of global carbon markets

- Focus on climate finance and technology transfer for developing countries

This created a more flexible and inclusive global system, encouraging countries like India to develop their own carbon-trading frameworks.

2. India's Domestic Evolution After Kyoto

India participated in Kyoto's Clean Development Mechanism (CDM) and became one of the largest suppliers of CERs globally.

- However, several issues emerged:
- Falling global prices of CERs
- Limited demand from developed countries
- Uncertainty about Kyoto's second commitment period

These shifts pushed India to move beyond CDM toward its own national market system.

3. NDC Commitments Created Pressure for Domestic Market Reform

After the Paris Agreement, India submitted its NDCs committing to:

- Reduce emissions-intensity of GDP by 45% by 2030
- Create an additional carbon sink of 2.5–3 billion tonnes of CO₂ equivalent through forests
- Achieve 500 GW of non-fossil fuel energy by 2030

Meeting these ambitious targets required a structured market mechanism to mobilize private investment, incentivize industries and channel finance into low-carbon technologies.

4. Learning from PAT: India's First Domestic Trading Experience

Before launching a national carbon market, India tested a sectoral trading system—the Perform, Achieve and Trade (PAT) Scheme, which:

- Reduced industrial emissions intensity by 15–25%
- Proved that market mechanisms work in India
- Built the institutional capacity of the Bureau of Energy Efficiency (BEE)
- PAT became the technical and administrative foundation for the next-generation carbon market.

5. Towards a Unified National Carbon Market

Drawing from the successes of the PAT scheme and the limitations of project-based mechanisms like CDM, India recognised the need for a comprehensive, nationally regulated carbon market. This led to policy discussions beginning in 2021 and culminated in the

notification of a new market architecture in 2023. The outcome was the establishment of a unified carbon-credit framework designed to align Indian industries with national climate goals. This transition set the stage for the Carbon Credit Trading Scheme (CCTS), launched in 2024, marking India's shift from fragmented mechanisms to an integrated, future-ready carbon market. Future of India's Carbon Market

As the world looks for effective mechanisms to address emissions, carbon pricing and carbon markets have emerged as critical tools. India, one of the world's fastest-growing economies and largest carbon emitters, is now entering a decisive phase of establishing an organized carbon market that balances development goals with climate responsibilities.

India's Carbon Market: A Transformational Step

India has taken significant strides toward establishing a structured carbon market with the introduction of the Carbon Credit Trading Scheme (CCTS) in July 2024. This marks the beginning of the Indian Carbon Market (ICM)—a framework designed to regulate emissions, support low-carbon technologies, and attract private investment.

Unlike traditional cap-based systems used in Europe, India's carbon market is rate-based. Instead of a hard limit on total emissions, industries are assigned emission-intensity benchmarks. This approach offers flexibility, acknowledging that India is both developing rapidly and addressing global climate commitments.

Initially, the scheme will cover nine energy-intensive sectors, including power, steel, cement, refineries and fertilizers. Industries that outperform the prescribed emission-intensity levels will receive Credit Certificates, which can be traded to other obligated entities. This reward-driven structure encourages efficiency without stifling growth.

Strengthening India's Voluntary Carbon Market

Alongside the compliance market, India is building a strong voluntary carbon credit ecosystem for sectors such as agriculture, afforestation, clean cooking and waste management. On 28 March 2025, the Ministry of Power approved eight crediting methodologies covering renewable energy, green hydrogen production, industrial energy efficiency, and mangrove afforestation. These will ensure transparency and quality in the voluntary carbon market and mobilise finance for community-led climate solutions. Projects like agroforestry, biogas plants, sustainable rice cultivation or mangrove restoration can become new income streams for farmers,

coastal communities and local organisations—linking environmental improvement with livelihood benefits.

Policy Backbone Behind the Carbon Market

India's carbon trading system is supported by robust policy measures:

- Energy Conservation (Amendment) Act, 2022 – Provides legal authority for issuing carbon credits and establishing a national carbon market.
- Perform, Achieve and Trade (PAT) Scheme – India's long-standing energy efficiency programme, which has successfully reduced emissions intensity by 15–25% across key sectors and will merge into the new market.
- National Green Hydrogen Mission – Backed by carbon credit methodologies to accelerate India's target of producing 5 million tonnes of green hydrogen annually by 2030.
- Renewable Energy Goals – India aims for 500 GW of non-fossil fuel energy capacity by 2030, ensuring the carbon market aligns with national clean energy ambitions.

These initiatives create a comprehensive ecosystem that integrates regulation, innovation and market participation.

Institutional Strength and Governance

To guide and regulate the Indian carbon market, the government has set up:

- National Steering Committee for the Indian Carbon Market (NSC-ICM) – The apex body responsible for overseeing market architecture, benchmarks and credit issuance guidelines.
- Bureau of Energy Efficiency (BEE) – Acts as the market operator, monitoring compliance, developing rules and ensuring transparency across the system.

Such governance ensures credibility, an essential requirement for domestic and international investor confidence.

How Indian farmers can get benefit?

Indian farmers can earn from carbon-credit mechanisms by adopting practices that capture or reduce greenhouse-gas emissions, such as

- tree plantation
- agroforestry

- soil-carbon enhancement
- biogas adoption
- sustainable farming methods

When these activities absorb or avoid carbon dioxide, they generate measurable carbon credits that can be sold in voluntary or government-supported markets, creating an additional income stream for farmers beyond traditional agriculture. This is especially beneficial for small and marginal farmers who can use boundary plantations, degraded land, or mixed farming systems to participate without affecting crop production.

To support this opportunity, the Government of India recently introduced the Green Credit Programme (2023) and expanded carbon-credit methodologies under the Carbon Credit Trading Scheme (CCTS) in 2025. These initiatives allow farmers, communities and organisations to earn tradable green credits for activities like afforestation, mangrove restoration, energy efficiency, clean cooking and sustainable agriculture. Several states, such as Uttar Pradesh, have also launched farmer-focused carbon-credit finance schemes that pay farmers for verified carbon sequestration from tree plantations. Together, these mechanisms open a structured pathway for rural households to benefit financially while contributing to India's climate-action

Conclusion

The fight against climate change demands solutions that balance environmental urgency with economic realities, especially for developing nations like India. The progression from the Kyoto Protocol to the Paris Agreement reflects a global shift toward shared responsibility and flexible climate commitments. For India, this evolution offered both an opportunity and a challenge: to continue its developmental trajectory while reducing emissions intensity and enhancing carbon sinks. The country's experience with schemes like CDM and PAT demonstrated that market-based mechanisms can drive cost-effective mitigation, provided they are supported by strong institutions and transparent rules. This learning ultimately paved the way for the Carbon Credit Trading Scheme (CCTS), a modern, rate-based carbon market tailored to India's economic structure.

CCTS positions India to accelerate industrial decarbonisation, attract clean technology investments and strengthen voluntary carbon markets across agriculture, forestry and renewable energy. Importantly, it creates new income opportunities for farmers and rural communities

through activities that sequester carbon and improve ecosystem health. As India moves ahead with its climate commitments, the carbon market will play a vital role in mobilising finance, encouraging innovation and ensuring that growth remains sustainable. Together, these efforts mark a significant step toward a resilient, low-carbon future for the nation.

Sources

- Dilmore, R. and Zhang, L. (2018). Greenhouse gases and their role in climate change. In Vyacheslav Romanov V. (Ed.), *Greenhouse Gases and Clay Minerals: Enlightening Down-to-Earth Road Map to Basic Science of Clay-Greenhouse Gas Interfaces* (pp.15-32). Switzerland: Springer Nature.
- Falloon, P., 2010. Global Warming and Climate Change: Ten Years after Kyoto and Still Counting. *Journal of Environmental Quality*, 39(3), p.1115.
- Parikh, J. and Parikh, K., 2004. The Kyoto protocol: an Indian perspective. *International Review for Environmental Strategies*, 5(1), pp.127-144.
- Press Information Bureau (2025 June 23). *Carbon Pricing in India: Market Mechanisms for Climate Leadership*. Retrieved from <https://www.pib.gov.in/PressNoteDetails.aspx?id=154721&NoteId=154721&ModuleId=3&reg=3&lang=2>
- Wikipedia, United Nations Framework Convention on Climate Change. https://en.wikipedia.org/wiki/United_Nations_Framework_Convention_on_Climate_Change

SI-SOLUBILIZING ORGANISMS: A BIOFERTILIZER TOOL FOR SUSTAINABLE AGRICULTURE

Article ID: AG-VO5-I12-49

***A Kanagavalli¹ and T Sherene Jenita Rajammal¹**

¹ Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

*Corresponding Author Email ID: akanagavalli23@gmail.com

Abstract

Silicon (Si) plays a vital role in strengthening plant growth and enhancing resistance against biotic and abiotic stress. Although abundantly present in the Earth's crust, most soil silicon exists in polymerised and insoluble forms that plants cannot directly absorb. Only after conversion into monosilicic acid (H_4SiO_4) does silicon become bioavailable. Natural silicate minerals, agricultural residues rich in phytoliths, and certain industrial by-products contribute to the soil silicon pool, but the release rate is often too slow to meet crop requirements—particularly for high Si-accumulating species like rice and sugarcane. Silicon-solubilising bacteria (SSB) and other Si-mobilising microbes offer a promising biological solution by secreting organic acids, chelators, and silicate-dissolving enzymes that liberate plant-available forms of silicon from insoluble silicates. The efficiency of silicon uptake is further improved when Si-solubilizers operate synergistically with mycorrhizal fungi and organic amendments, which enhance root access, microbial activity, and soil physical properties. This integrated biological approach supports sustainable nutrient cycling and significantly improves plant tolerance to salinity, drought, heavy metals, and lodging stress. Therefore, the application of silicon-solubilizing microorganisms, along with mycorrhiza and organic amendments, represents an eco-friendly and effective strategy to improve soil fertility, crop productivity, and resilient farming systems.

Keywords: Silicon, Feldspar, Monosilicic acid, Mycorrhizal fungi, Phytoliths

Introduction

Silicon is essential for sustaining growth and improving resistance to biotic and abiotic stressors. Monosilicic acid, the accessible form of silicon that plants absorb, is released into the soil solution when the polymeric insoluble silica found in soils is dissolved during weathering. The silicate mineral sand, quartz (Pure SiO_2), kaolinite, mica, feldspar, and other clay minerals (aluminium, magnesium, calcium, sodium, potassium, or iron) are the main forms of silicon found in the earth. Since silicon is found in the soil in an unusable polymer form, plants absorb it once it has been depolymerised. Si and silica nanoparticles can be utilised as fertilisers, insecticides, and herbicides in agriculture and are good for plant growth and protection. Although there are many bacteria in soil, only a small number of them known as silica solubilising bacteria (SSB) are identified to release Si from natural silicates (Joshi et al., 2023).

For rice, sugarcane, and other graminaceous plants, silica is generally thought to be necessary for photosynthesis, plant erectness, and disease and pest resistance. Silicon has been shown to stimulate specific enzyme reactions, such as invertase, which increases the generation of sucrose in sugarcane and decreases phosphatase. It also increases the availability of vital high-energy precursors required for cane growth. It is a crucial component for sustained rice production from an agronomic standpoint. The Si concentration of rice, a common plant that accumulates Si, Straw's percentage of dry weight varies greatly (2 to 10%), but it is often between 5 and 6%. It is typically several times greater than that of vital macronutrients like N, P, and K. A rice crop with a grain yield of 5 t ha^{-1} is predicted to remove 230 to 470 kg ha^{-1} Si from the soil. Soil contains silicon in an inaccessible polymerised form, despite the element being widely available on the earth's crust. Plants can access silicon because of microorganisms and chemical interactions in the soil (Chandrakala et al., 2019).

Sources of Silicon in Soil

Silicon is one of the most abundant elements in the Earth's crust and occurs mainly in the form of silicate minerals. In soils, its availability depends on the parent material and degree of weathering. Primary sources of silicon include quartz, feldspars, mica, and clay minerals, which gradually release monomeric silicic acid (H_4SiO_4), the form that plants absorb. Agricultural residues such as rice husk, sugarcane bagasse ash, and other phytolith-rich plant materials also contribute to the silicon pool when returned to the soil. Additionally, industrial by-products such as steel slag, calcium silicate, and coal-derived sintered products can provide a slow-release

supply of plant-available silica.

Silica Solubilizing Bacteria

In addition to effectively solubilising insoluble types of silicates, silicate solubilising bacteria (SSB) can also effectively solubilise potassium and phosphates, improving soil fertility and plant production. Silicon helps plants in a number of other ways by quickening growth, giving leaves stiffness to maximise leaf surface area for photosynthesis, and reducing the impact of abiotic stresses including drought, salt, and metal toxicity in a variety of plants, such as wheat, rice, sugarcane, cucumber, tomato, citrus, and barley.

How Si-Solubilizers Release Plant-Available Forms of Silicon

Even though soils contain abundant silicate minerals, most of the silicon remains in insoluble forms that plants cannot use. Silicon-solubilizing microorganisms (bacteria and fungi) play a crucial role in converting these minerals into a soluble form that can be absorbed by plant roots. These microbes colonize the rhizosphere and secrete a variety of **organic acids, such as citric acid, oxalic acid, malic acid, and gluconic acid**. These acids reduce the pH in the mineral micro-environment and break the bonds holding silicon within silicate structures. As a result, insoluble silicates dissolve and release **monosilicic acid (H_4SiO_4)** the only form of silicon that plants can uptake. Apart from organic acid production, Si-solubilizers also release **chelating agents, protons (H^+), and extracellular polysaccharides**, which further weaken mineral lattices and accelerate the dissolution of silicates. Some microbes, particularly *Bacillus* and *Aspergillus* species, also produce **silicate-dissolving enzymes**, which facilitate the breakdown of crystalline forms of silicon. Through these mechanisms, Si-solubilizing microorganisms ensure a continuous supply of plant-available silicon in the root zone, improving nutrient uptake, strengthening cell walls, and enhancing the plant's ability to withstand salinity, drought, heavy metal toxicity, and lodging stress.

Synergistic Action of Si-Solubilizers with Mycorrhiza and Organic Amendments

The efficiency of silicon availability in soil increases significantly when silicon-solubilizing microorganisms work in combination with mycorrhizal fungi and organic amendments. Each of these components contributes uniquely to nutrient transformation and root physiology, and together they form a powerful biological network for improving soil and plant health. Mycorrhizal fungi extend their hyphal network deep into the soil, reaching mineral surfaces and microsites that plant roots alone cannot access. This expanded surface area

enhances the mobilization and transport of nutrients, including silicon. Meanwhile, Si-solubilizing microorganisms release organic acids and chelating compounds that dissolve silicate minerals and convert them into plant-available monosilicic acid. When mycorrhiza absorb this soluble silicon, they act as efficient carriers, transferring it to plant roots through their symbiotic association.

Organic amendments such as compost, FYM, green manure, crop residues, and biochar further amplify this interaction. They provide energy sources for microbial proliferation, improve soil structure, and increase moisture retention all of which create a favorable environment for both Si-solubilizers and mycorrhizal fungi. Organic materials also contain phytoliths and amorphous forms of silica that gradually contribute additional silicon to the soil pool. Together, this synergistic system enhances nutrient cycling, reduces soil pH in sodic soils, promotes root growth, and improves plant tolerance to salinity, drought, and other abiotic stresses. As a result, crops exhibit better vigour, higher biomass, stronger stems, and ultimately higher yield efficiency. This biological integration promises a sustainable and eco-friendly strategy for soil fertility management and silicon-based stress mitigation in agriculture.

References

- Joshi, A., Mahawar, S., Kajala, R., Chauhan, S. and Jain, D., 2023. Importance of silica solubilising bacteria in agriculture. *crops (Han and Lee, 2005; Tripti et al., 2017)*, 18, p.38.
- Chandrakala, C., Voleti, S.R., Bandeppa, S., Sunil Kumar, N. and Latha, P.C., 2019. Silicate solubilization and plant growth promoting potential of *Rhizobium* sp. isolated from rice rhizosphere. *Silicon*, 11(6), pp.2895-2906.

VALORIZATION OF COAL COMBUSTION RESIDUES: A NOVEL PATHWAY FOR VALUE-ADDED PRODUCT DEVELOPMENT

Article ID: AG-VO5-I12-50***A Kanagavalli¹ and T Sherene Jenita Rajammal¹**

¹ Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India,

*Corresponding Author Email ID: akanagavalli23@gmail.com

Introduction

Coal accounts for more than 26% of the world's primary energy and is the world's greatest energy source. With a total consumption of 161.47 EJ in 2022, (IEA 2023). In recent years, renewable energy sources such as wind, solar, and biomass have received more attention worldwide and are frequently suggested as possible alternatives to fossil fuel (Tang et al., 2024). In addition to occupying of large amount of land, the massive coal combustion products (CCP) buildup results in serious safety and environmental problems, such as soil degradation, spontaneous combustion, the release of hazardous gases, heavy metal contamination, and geological hazards (Sun et al., 2021). As a result, many nations have been actively investigating different utilization strategies to get rid of the dangers caused by CCP accumulation.

The creative use of coal gangue as value-added products is currently the subject of extensive research. CCP can be used as a soil conditioner, slow release fertilizer and soil amendment etc. The plant will gradually receive a supply of the three main macronutrients (N, P, and K) through the impregnation of fertilizers into the charcoal. According to Han et al. (2021), coal gangue (CCP) -derived soil conditioner is more compatible with soil than artificial synthetic and microbial soil conditioner, allowing for its widespread and extended use while attaining mass-scale production at a low cost. Large amounts of accumulated coal gangue can be used to improve and restore large tracts of potentially accessible deteriorated soil globally, providing a viable way to concurrently address the issues of soil degradation and coal gangue management.

Modification methods for CCP

To optimise its performance, activate its good ingredients, improve its retention of water and fertiliser, and reduce pollution and biological toxicity, the raw coal gangue needs to be modified appropriately. Currently, mechanical, chemical, microbiological, and thermal modification are typical ways to modify CCP.

Mechanical modification

The term "mechanical modification" describes the physical and chemical changes that occur when a material is subjected to mechanical forces. These changes include the reduction of particle size, the enhancement of specific surface area, the destruction of particle structure, the fracture of inter-particle hydrogen bonds and the Al–O–Si bonds of kaolinite, the promotion of defects or displacement of the lattice or even the amorphous state, and the activation of advantageous elements.

Chemical modification

The CCP are chemically modified using either an acidic solution (like HNO_3 , HCl) or an alkaline solution (like Na_2CO_3 , NaOH , KOH). This change modifies the CCP surface activity, crystal structure, and chemical bonding. As a result, coal gangue's pore size distribution, active sites, and adsorption ability are significantly improved.

Microbiological modification

Microbiological modification uses the metabolic processes of microorganisms to break down the minerals in CCP, releasing nutritional elements and eventually producing microbial fertilisers. Both phosphate solubilising bacteria (PSB) and arbuscular mycorrhizal fungus (AMF) play a part in the breakdown of organic matter and the consequent release of nutrients. PSB's role was to transform both organic and inorganic phosphorus into soluble forms, which logically increased the availability of phosphorus in minerals and encouraged plant growth.

Thermal modification

The most common modification technique, according to the literature, is thermal activation, which is used to break down polymerised long chains of silicon tetrahedrons and alumino-oxygen octahedrons at high temperatures to increase the activity of beneficial elements. Temperature and time are the two main variables affecting thermal activation efficiency.

Hydrothermal modification

The hydrothermal modification method uses an aqueous solution as the reaction medium and is carried out in a specialised closed reaction vessel. A sub-critical water state is created in high temperature and pressure environments in the vessel, encouraging several coal gangue conversions, such as hydrolysis, depolymerisation, polymerisation, isomerisation, dehydration, aromatisation, condensation, and other transformation events.

Combined Modification

To attain maximum benefits and greatest effectiveness in actual applications, a mix of several modification techniques is advised. Chemically aided mechanical milling, heat activation in conjunction with chemical modification, and mechanical pulverisation in conjunction with microbiological modification, the hydrothermal approach combined with chemical, mechanical, and thermal alteration , and chemical reagent aided hydrothermal treatment have garnered significant interest. The shortcomings of a single technology can be effectively addressed by the combined technology, but it requires complex and multidimensional operational procedures.

References

- Tang, T., Wang, Z., Chen, L., Wu, S. and Liu, Y., 2024. Opportunities, challenges and modification methods of coal gangue as a sustainable soil conditioner—a review. *Environmental Science and Pollution Research*, 31(48), pp.58231-58251.
- Sun, Y.Q., Xiao, K., Wang, X.D., Lv, Z.H. and Mao, M., 2021. Evaluating the distribution and potential ecological risks of heavy metal in coal gangue. *Environmental Science and Pollution Research*, 28(15), pp.18604-18615.
- Han, X.N., Dong, Y., Geng, Y.Q., Li, N. and Zhang, C.Y., 2021. Influence of coal gangue mulching with various thicknesses and particle sizes on soil water characteristics. *Scientific Reports*, 11(1), p.15368.

APPLICATION OF ARTIFICIAL INTELLIGENCE IN FOOD PROCESSING

Article ID: AG-VO5-I12-51***P. Preetha¹, P. Sudha², G. Amuthaselvi³, S. Parveen⁴, and R. Arulmari⁵**

Teaching Assistant (FPE)¹, Assistant Professor^{2,3,4,5}, Dept. of Food Process Engineering,
Agricultural Engineering College and Research Institute, TNAU, Coimbatore – 641003, India

*Corresponding Author Email ID: preethafoodtech@gmail.com

Abstract

The global food processing industry faces escalating challenges regarding efficiency, sustainability, and stringent food safety regulations. This article systematically examines the transformative applications of Artificial Intelligence (AI), specifically Machine Learning (ML), Computer Vision (CV), and Robotics, across the entire food processing value chain, highlighting both current capabilities and future potential. We categorize and analyze AI's impact in several critical domains: i) Enhanced Quality Control and Inspection, where CV systems perform rapid, non-destructive defect detection (e.g., foreign material identification, grading, sorting) with superior accuracy and consistency; ii) Optimized Process Management, where ML models predict equipment failures (predictive maintenance) and fine-tune operational parameters to minimize energy use, reduce waste, and ensure consistent product attributes; and iii) Advanced Food Safety and Traceability, leveraging AI to analyze complex sensor and microbial data to proactively mitigate contamination risks and provide immutable, real-time supply chain transparency. The successful implementation of these technologies promises substantial benefits, including significant cost reductions, improved resource utilization, and an overall increase in food security. Ultimately, AI is positioned as a critical, enabling technology for developing smart, resilient, and sustainable food manufacturing systems capable of meeting 21st-century demands.

Introduction

In recent times, there has been a lot of speculation about food production and the factors

that influence commodity markets in the demand-supply chain. These insights have raised serious concerns about mankind's ability to sustain such food demand and feed the growing population without further exploiting the world's resources and damaging the environment. There are several factors to consider when addressing this issue, including the rapid growth in the world's population, the gradual increase in income levels in developing countries, global warming, and other environmental hazards caused by mankind over the decades. The demand for food supplies is directly proportional to the growing population, and the Food and Agricultural Organization (FAO) of the United Nations has estimated that the population could reach around 9.1 billion by 2050. This estimate highlights the need for a 70% increase in food supply worldwide and nearly double in developing countries. Despite this, undernourishment remains a problem, with 793 million people, or one in every nine people in the world, lacking food for their daily needs. According to FAO data, few Asian countries still suffer from undernourishment, with India and China being the two biggest nations affected due to their growing population and economic advancements.

In recent times, the food industry has witnessed significant advancements that have paved the way for novel food production and technical processing methods. Over the past five decades, there has been a growing demand for various types of food, including functional foods, which have been identified as a key component of a healthy lifestyle. To meet the market's demand and achieve rapid production, the food industry has adopted several food processing techniques. Initially, modern machinery for cultivation and food processing were used, which were later replaced by smart machines and production lines. The question remains whether these innovations can sustainably feed the rapidly growing population and avoid the inevitable. However, with the increase in demand and proportional increase in technical innovations, it seems possible. In the last decade, there has been a significant shift in business models and investments, with the rise of IR technologies such as artificial intelligence and computer vision robotics. These latest technologies could be a possible tool in dealing with future demand for sustainable food supply.

Artificial Intelligence role in Food

Artificial intelligence (AI) or machine learning (ML) is a relatively recent computational tool that has found widespread application in solving real-world problems. AI has been employed in various domains, including modeling, classification, and data analysis. Notable

applications include numerical processing, control planning, communication advancements, interpretation of pyrolysis, gas chromatography, mass spectrometry, and HPLC data, as well as pattern recognition in RNA, protein, and DNA structures. AI has also been utilized for predicting microbial growth, biomass, and the shelf life of food products, as well as for microbial identification.



In the food sector, AI has been particularly employed in food science and processing to enhance performance. Techniques such as neural networks, fuzzy logic, and genetic algorithms have been utilized to improve sorting and quality control of food samples, as well as for wine analysis. Additionally, AI plays a crucial role in maintaining hygiene and ensuring high standards in the food industry through systems like CIP (Clean In Place) and COP (Clean Out of Place). These systems, known as SOCIP (Self-Optimizing Clean In Place), rely on AI to function effectively. The global population is increasing rapidly, leading to challenges in food production due to diminishing agricultural lands, climate change, and pollution. These factors have adverse effects on food production, the environment, and human health, resulting in a lack of essential nutrients for billions of people worldwide. To address these issues, holistic approaches can be employed to develop strategies that promote progress and achieve better food security.

Farmers have embraced new harvesting techniques driven by public demand in order to achieve high yields through the use of artificial intelligence. The advancement of horticulture and its associated innovations have led to various new research opportunities. The implementation of AI in agriculture involves data analysis, decision-making, and effective operations through the utilization of machine power. This enables early detection of crop diseases, provision of necessary nutrition to livestock, and optimization of farming inputs and profits based on market demand and supply.

Several technologies, such as pest control management and pesticide information, have been developed to assist farmers in increasing their yields. Bayesian Network (BN) is a viable solution to address these challenges (How et al., 2020). The advantage of using BN is that it does not require any software skills, making it accessible even to beginners.

By incorporating prior information into data analysis, the Bayesian methodology enables simulations and predictive inferences without relying on traditional frequentist approaches or null hypothesis tests. This approach facilitates the calculation of mutual information (MI), which measures the probability between data distributors (How et al., 2020). The application of these procedures in BN allows for the examination of interactions between theoretical factors in the Global Food Safety Initiative (GFSI). Moreover, these Bayesian models have significant relevance in the field of food safety worldwide, as they provide user-friendly representations. Therefore, AI plays a crucial role in the food industry, not only in ensuring quality and food security but also in various other areas such as manufacturing, packaging, and cleaning.

Artificial intelligence in dairy sector

Milk is transported from various production centers to milk plants through milk trucks, where it undergoes pasteurization to remove bacteria and improve its shelf life. The ideal pH value for milk is 6.7, and refrigeration is necessary to prevent spoilage. To address this issue, a wireless sensor network with artificial intelligence concepts is required. Artificial intelligence also plays a role in milking cows, where Automated Milking Machines or milking robots are used to reduce the time and effort required for manual milking. These robots are equipped with electronic tags to identify cows and provide feed, and use advanced technologies such as laser scanners and ultrasound to test milk for diseases. With the help of computer vision and machine learning, these robots can navigate and learn from humans, making them an integral part of the dairy industry.

Artificial intelligence in beverages/soft drinks

Drinks can be categorized into three main groups: alcoholic drinks, non-alcoholic drinks, and hot drinks. Alcoholic beverages encompass beer, wine, and spirits, while non-alcoholic beverages include juices, carbonated water, milk, and soft drinks like Coca Cola, Thumbs Up, and Miranda. Hot beverages consist of tea, coffee, and hot chocolate. The fermentation process of beer begins by introducing yeast to the aerated wort. The yeast then consumes the

nutrients present in the wort and undergoes growth. Simultaneously, the yeast aids in the production of alcohols and metabolites. This fermentation process concludes when the sugar levels in the wort decrease to a predetermined concentration, resulting in a lighter wort and higher alcohol content.

Several factors require regulation during the fermentation process, including oxygen content, temperature, and pitching rate. Additionally, the composition of the wort and the condition of the yeast can also impact the fermentation process. To compensate for any inconsistencies in yeast and wort, distilleries may adjust the pitching rate or elevate oxygen levels and temperature. Traditionally, continuous monitoring of the fermentation process has been challenging. However, advancements in technology, particularly the utilization of artificial intelligence (AI) and its programmed tools, enable the monitoring and control of the brewery process.

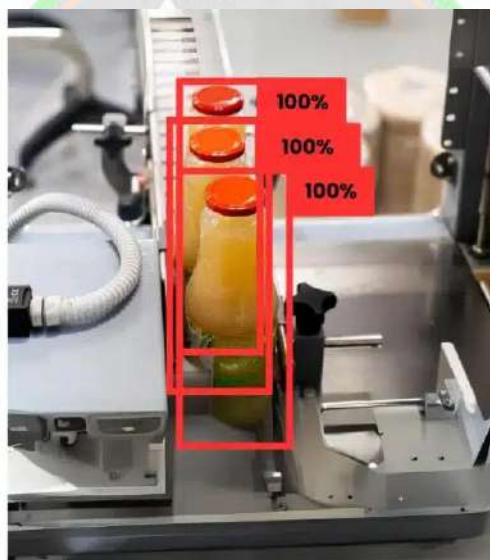


Image acquisition in which they will take picture with mobile built software in the grape fields just before one week of harvest for segregation of grapes cluster compactness. This compactness can be rated manually by panel experts under the standards of International Organization of Vine and Wine OIV 204. There are nine classes for rating the cluster compactness. Second step is image processing which is a barrier to the third segmentation step that requires more data of each cluster. This data will provide the information about rotten, unqualified clusters by using different methods or algorithms such as K-means, Gaussian, cross validation.

An electronic nose is an innovation for the examination of smell, it works on the concept of mammalian olfactory by utilizing gas sensors that can be used in wine and coffee industries for smelling. . Electronic nose is utilized in food industries and beverages to control the quality of the products. The efficiency of roasted coffee is identified by coffee cupping method, in accordance with the standard set by the Technical Standards Committee of the Speciality Coffee Association of America (SCAA). Quality of tea can be estimated by using e-tongue. Theaflavin (TF) and Thearubigin (TR) are flavouring components. Pu-erh tea tests of different assessment types and backgrounds have always been broken utilizing e-tongue assessment and different instrumental methods, including synthetic examination and electronic tongue.

Artificial intelligence in cutting and sorting of fruits and vegetables

Fruits and vegetables play a significant role in the nation's agricultural sector. However, their production has been declining steadily due to improper cultivation practices, lack of maintenance, losses during harvesting and post-harvesting, and the rising cost of labor. To address these challenges, the automation method has been adopted to enhance efficiency and reduce losses. This method utilizes computer vision (CV), a component of artificial intelligence (AI), which employs various software programs to classify fruits and vegetables based on their quality and identify any damages they may have.



Among the non-destructive methods used to detect diseases in fruits, X-ray imaging technology stands out as one of the most effective. For instance, X-ray imaging techniques, along with Artificial Immune Systems (AIS) developed by Ahmad et al. (2005), are employed to assess the quality of mangoes. Another technique known as Image Processing analyzes, detects, and segments the physical properties of mangoes, such as color, shape, size, and surface area, using images.

Furthermore, Principal Component Analysis (PCA) and Linear Discriminate Analysis (LDA) suggest that the best efficiency in mango yield is achieved during week 7 or 8. Competitive Learning Neural Network classifiers have also been formulated, utilizing fuzzy image processing, to analyze and calculate the rating of mangoes. The crucial step in this process is to accurately detect and sort the mangoes, aiming for an accuracy rate of over 80%. It is worth noting that these techniques are not limited to mangoes alone but are also applicable to other fruits.

Artificial intelligence in bakery

The baking industry, like many others, is experiencing a surge in automation. Bakery products come in various shapes, sizes, and colors, and grading plays a crucial role in handling and packaging them. In the past, human visual inspection was the primary quality assurance method. Bread making involves several processes, including the introduction of living microorganisms such as yeast into the dough. Any imperfection in these steps can negatively impact the quality of the bread. The industry's priorities include proper production arrangement, efficient resource utilization, and the implementation of automatic control systems (ACS) to improve product quality, reduce costs, and increase profits. The introduction of ACS in the bread making industry can boost productivity and efficiency, while also saving energy and fuel. Another approach to improving bread product quality is to enhance resource efficiency and increase the availability of authentic information. ★ ★ ★



The robotic technology complex comprises an automated control system that effectively manages various aspects of the dough preparation process. These include monitoring the rheological properties of the sourdough and dough, determining the lifting force exerted on the

dough, assessing the active acidity of the sourdough and dough, evaluating the smell, and gauging the forming ability of the dough. evaluating the smell, and gauging the forming ability of the dough. Additionally, the complex controls the duration of dough proofing, the proofing temperature, the humidity in the proofing case, and the weight of the dough through the use of sensors

Furthermore, the system of sensors and the visualization system indirectly regulate the porosity of the bread, its acidity, dimensional stability, moisture content, temperature of the soft part center, and the duration of baking the dough. These sensors and the visualization system contribute to an intellectual system that supports managerial decision-making. This system utilizes information from sensor blocks, such as the database, knowledge base, training base, output block, and expert systems, to modify the operating modes of ultrasonic systems. By doing so, the complex optimally manages the impacts on heterogeneous technological environments. Moreover, the expert system of product quality control evaluates the parameters of the raw materials, thereby enhancing the properties of flour, sourdough, and dough for fortification purposes in bread production. This comprehensive approach not only ensures efficient control over the dough preparation process but also improves the overall quality of the final product.

Artificial intelligence in restaurant

The utilization of AI robots has gained global recognition and has been implemented not only in industrial manufacturing but also in the service industry. A wide range of robots with different functionalities have replaced human workers in various areas such as guiding, reception, and delivery services.



In the restaurant industry, robots are utilized for tasks such as washing, cutting vegetables, sorting dishes, serving, and cleaning. The robots used in restaurants have distinct functions and characteristics. The majority of robots used in the back of the house are industrial robots, while service robots are deployed in the front of the restaurant. The waiter robot, for instance, is composed of a base and an automatic dumb waiter, which has three stages and has replaced human waiters. These robots also assist in keeping the food clean and warm and ensuring timely delivery to customers. The energy source used for these robots consists of a pair of 24V lithium polymer (LiPo)

To enable the robots to access tables at a height, a specific type of motor is connected between the base and dumbwaiter, which lifts it to the required height. In the Robot Operating System (ROS), a mathematical model and programming code are created and applied to the robot model and the original one. The robotics are controlled by visualized maps that display the complete restaurant table layout. These maps can be generated from a ground plan or built using Simultaneous Localization and Mapping (SLAM) algorithms.

The Adaptive Monte-Carlo (AMCL) is used to locate the robot model within the map.

Restaurants are generating vast amounts of data through various software packages that manage a wide range of tasks, including food delivery scheduling, staff shifts, reservations, and inventory management. The implementation of artificial intelligence (AI) in restaurants has proven beneficial in reducing waste, improving the supply chain, and enhancing home delivery services. One of the AI applications in the restaurant industry is the use of chatbots, which offer automated and personalized customer service, as well as handle payment and order collection. These chatbots do not require users to download any additional applications and have minimal setup costs. Digital menu boards have also simplified the process of updating prices and items, eliminating the need for manual changes. Chatbots, which are online programs capable of engaging in human-like conversations, rely on machine learning (ML) and natural language processing (NLP) to understand and respond to customer queries. They can provide answers to frequently asked questions, assist customers with placing or tracking orders, and facilitate payment processing. Furthermore, chatbots continuously learn from their interactions with customers, allowing them to improve their performance over time as they are exposed to more data. The key advantage of using chatbots in restaurants is their ability to operate without any downtime, sick leave, or vacation days, providing immediate assistance to customers at any time.

Artificial intelligence in 3 D printing

3D printing is a form of additive manufacturing that has undergone significant advancements since the late 1980s, transforming from a mere prototyping tool into a complex ecosystem of diverse technologies. While the specific techniques employed in 3D printing may vary, they all share common applications. This technology primarily involves the layer-by-layer construction of materials, such as metal powder, which is melted using lasers or ultraviolet light to form liquid polymers. The versatility of this technology enables the creation of intricate and complex shapes. Moreover, the ability to generate digital designs facilitates decentralized production and allows for the customization of parts. In a similar vein, robotics, which are akin to 3D printers, have experienced a surge in development due to the ease of electronics integration, the availability of cloud computing resources, and the utilization of high-quality sensors. In the past, robots were prohibitively expensive and primarily utilized in heavy manufacturing industries, such as automotive production. Typically, companies would invest a minimum of \$1,000,000 to incorporate robotics into their production processes. The convergence of 3D printing and robotics has particularly revolutionized the confectionery industry, attracting attention from companies seeking enhanced efficiency and productivity.



Conclusion

With the continuous growth of the global population, there has been a noticeable migration of individuals from rural areas to urban centers. This urbanization trend has led to an increased demand for food and food-related products. In response to this demand, advancements in science and technology have emerged to address the need for food supplementation. In order to meet the expectations of consumers, numerous innovations have been developed. To cater to

the desires of consumers, artificial intelligence (AI) has emerged as a valuable tool in optimizing various factors involved in the development of a healthy and hygienic diet. This explores the role of AI in different sectors of the food industry. Extensive research has been conducted to examine the scope of robotics in the food and beverage sector, and the findings have been critically analyzed and discussed. Furthermore, significant progress has been made in the field of 3D printing, which has the potential to revolutionize the entire food business, from manufacturing to service.

Reference

- Antony, P. Sivraj. (2018). Food delivery automation in restaurants using collaborative robotics. Proceedings of the international conference on inventive research in computing applications (ICIRCA), IEEE (2018), pp. 111-117.
- F. Brian, (2015). 3D printing, robotics, and the future of confections (2015). <https://www.candyindustry.com/articles/87024-d-printing-robotics-and-the-future-of-confections>.
- J. Ervin, (2017). User acceptance of baking automation: An extension of the unified theory of acceptance and use of technology (UTAUT) to manufacturing. Doctral Dissertation, Northcentral University (2017), Article 10638279.
- F.C. Godoi, S. Prakash, B.R. Bhandari. (2016). 3D Printing technologies applied for food design: Status and prospects. *Journal of Food Engineering*, 179 (2016), pp. 44-54.
- R. Hafiz, M.R. Haque, A. Rakshit, M.S. Uddin. (2020). Image-based soft drink type classification and dietary assessment system using deep convolutional neural network with transfer learning Journal of King Saud University-Computer and Information Sciences.
- C. Guo, M. Zhang, B. Bhandari. (2019). Model building and slicing in food 3D printing processes: A review *Comprehensive Reviews in Food Science and Food Safety*, 18 (2019), pp. 1052-1069.
- H. Jia, Y. Zhu, G. Li, Y. Wang, & Z. Ma. (2024). Applications of Artificial Intelligence in Food Industry. *Future Foods*.
- B. A. Mengistu, & S. R. Ashe. (2025). Review on Artificial Intelligence Powered Food Processing: Enhancing Safety and Sustainability, *Asian Science Bulletin*.

- S. R. Noutfia, & E. Ropelewska. (2024). Highlighting the application of image analysis to classify date fruits into categories based on the drying processes, *Sensors*.
- Y. Ding, D. W. Sun, & Q. Wang (2023). Compositional Analysis using Deep Learning and Near-Infrared Spectroscopy. *Journal of Food Engineering*.
- Z. Ge, et al. (2024). Future of AI applications in the food industry. PMC – NIH.
- A. Kumar, (2024). The fusion of IoT, block chain, and machine learning in food safety. *International Journal of Food Science and Technology*.
- F. Tao, et al. (2023). AI-driven market trend analysis for new food product development. *Trends in Food Science & Technology*.
- A. Kumar, The fusion of IoT, block chain, and machine learning in food safety. *International Journal of Food Science and Technology*, 2024.



COMPONENTS OF INTELLECTUAL PROPERTY RIGHTS

Article ID: AG-VO5-I12-52

¹Sakthi Anand, M. K., ²V. Krishnan*, ²N. Swaminathan, ²V. Ramesh and ³J. Arathi

¹Ph. D. Scholar, ²Faculty & ³PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India
Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Intellectual Property Rights (IPR) are special legal rights that protect creations of the mind, like inventions, art, music, designs, and symbols. These rights give creators—or people they authorise—the ability to control how their work gets used and to benefit from it, often for a set period. They are legal protections granted to creators and inventors for their original creations and innovations. These rights enable creators to control how their inventions, artistic works, brands, and designs are used, ensuring they can benefit from their efforts. Awarded by governments, IPR encourages innovation, creativity, and economic growth by rewarding creators while ultimately benefiting society by promoting new ideas and reliable products.

As clearly defined by the World Intellectual Property Organisation (WIPO), *intellectual property* includes things made by human imagination and intelligence, such as Inventions (e.g., machines, processes), Literary and artistic works (books, music, films, art), Designs (industrial designs, logos) and Symbols, names, and images used in business

IP laws ensure creators get recognition and can earn from their work, while also encouraging society's innovation and creativity. The system aims for *balance*—rewarding inventors while serving the public interest. As per the World Intellectual Property Organisation (WIPO) definition, intellectual property refers to creations of the mind, inventions, literary and artistic works, symbols, names, images and designs used in commerce.

Broadly, intellectual property is divided into two categories. The first category covers industrial property, which includes patents, industrial designs and trademarks, all of which have

industrial applications. The other refers to copyright laws, which are applied to such things as literary, dramatic and artistic works; rights relating to performing artists, the production of phonograms and rights of broadcasters in their radio and television programs.

COMPONENTS OF INTELLECTUAL PROPERTY

Intellectual property is commonly classified into two main categories: viz.,

Industrial Property: This includes inventions protected by patents, trademarks, industrial designs, and geographical indications. These generally relate to commercial and industrial applications.

- **Copyrights and Related Rights:** These cover original literary, musical, and artistic works, cinematographic films, broadcasts, and performances.

Within these categories, seven distinct types of rights offer tailored protection for various creations: patents, copyrights, trademarks, industrial designs, IC layout designs, geographical indications, and trade secrets or undisclosed information.

01. PATENTS: PROTECTING NEW INVENTIONS

A patent grants an inventor an exclusive right by the government to make, use, manufacture, and market their invention for a limited period, typically 20 years from the filing date. This exclusivity means no one else can legally exploit the invention without the patent holder's consent. The Essential Features of Patents includes,

- **Exclusive Rights:** The inventor gains the sole authority to commercialise their invention.
- **Patentability Requirements:** Inventions must be novel, involve an inventive step, and be industrially applicable. Examples include new chemical processes, drugs, mechanical devices, electronic circuits, surgical instruments, or vaccines.
- **Territorial Nature:** Patents are valid only in the countries where they are granted. Inventors must apply separately in each country where protection is sought, paying corresponding fees.
- **Transferability:** Patents are a form of property and can be sold, gifted, licensed, or inherited.
- **Limitations and Conditions:** Although patent rights confer broad exclusivity, usage might still be regulated by other national laws concerning safety, health, or security. Furthermore, existing patents could restrict the use of new inventions.

- **Revocation:** Governments can revoke patents under exceptional circumstances, even if the patent has been transferred or exploited.

Patents play a vital role in incentivising innovation by providing inventors with time-limited monopolies that allow them to recoup research and development investments.

02. COPYRIGHTS: SAFEGUARDING CREATIVE EXPRESSIONS

Copyright provides creators protection over original literary, musical, artistic, dramatic, and audio-visual works. It covers everything from books, songs, and paintings to films, sound recordings, photographs, software, and broadcasts.

- **Automatic Protection:** Copyright arises automatically when a work is fixed in a tangible form, meaning the creator does not need to register to acquire rights, although registration helps enforce those rights.
- **Scope:** Includes literary works (books, articles, computer programs), artistic works (paintings, photographs), musical compositions, cinematographic films, sound recordings, and broadcasts.
- **Duration:** In countries like India, the creator's lifetime plus 60 years generally governs the length of protection for literary works. For films, sound recordings, photographs, and government or anonymous publications, the term is 60 years from publication. Broadcast protection lasts 25 years.
- **Rights Conferred:** Creator's control of copying, distribution, adaptation, public performance, and broadcasting, preventing unauthorised use.

Copyright encourages cultural and educational development by allowing authors and artists to earn recognition and financial rewards from their labour.

03. TRADEMARKS: PROTECTING BRANDS AND IDENTIFICATION

A trademark is a distinctive sign that identifies the goods or services of one enterprise from those of others. It can be a word, logo, symbol, shape, colour, sound, or even a combination of these elements. The fundamentals of Trademarks are,

- **Purpose:** Helps consumers recognise and trust the source of a product or service.
- **Forms:** Includes words, letters, numerals, logos, drawings, shapes, packaging designs, colours, and sounds.
- **Special Types:**

- **Collective Marks:** Used by members of an association to indicate membership or shared standards.
- **Certification Marks:** Show that products meet certain standards or quality (e.g., ISO9000).
- **Exclusive Rights:** Trademark owners have the exclusive right to use the mark and prevent others from using confusingly similar marks in related markets.
- **Brand Value:** Trademarks protect the reputation and goodwill of businesses, helping maintain customer trust and market identity.

By safeguarding brands, trademarks contribute crucially to business equity and consumer protection.

04. PROTECTION OF INTEGRATED CIRCUIT LAYOUT DESIGN (IC LAYOUT)

The protection of semiconductor integrated circuit (IC) layout designs is governed in India by the Semiconductor Integrated Circuits Layout-Design Act, 2000. This specialised legal framework protects the intellectual property embedded in the intricate layout of transistors and other circuitry elements on semiconductor chips.

What is Protected? The layout design includes the arrangement of transistors, circuitry elements, and the lead wires connecting these elements, expressed in any form in a semiconductor IC. A semiconductor IC is a product comprising transistors and circuitry elements inseparably formed on or inside a semiconductor or insulating material, designed to perform electronic functions.

Key Features of Protection

- **Term:** Registration protection lasts for 10 years from the date of filing.
- **Territorial Scope:** Protection applies within India, consistent with international conventions.
- **Registration Requirements**
 - i. The layout design must be original.
 - ii. It must not have been commercially exploited in India or any convention country prior to registration.
 - iii. It must be distinctive and capable of being distinguished from other registered designs.

- **Effect of Registration:** The registered proprietor gains the right to prevent unauthorized copying or commercial exploitation of the layout design.

This Act fosters innovation and investment in the semiconductor sector by providing a secure legal right over highly technical and valuable IC designs.

05. GEOGRAPHICAL INDICATIONS (GIs)

Geographical Indications (GIs) denote a type of intellectual property that identifies a product as originating from a specific geographical location, where the product's quality, reputation, or characteristics are essentially linked to that origin. GIs apply to agricultural, natural, or manufactured goods that have unique qualities attributable to their place of origin. For manufactured goods, at least one stage of production, processing, or preparation must occur in the designated geographic area.

Legal Framework in India

- Governed by the Geographical Indications of Goods (Registration and Protection) Act, 1999.
- Registration is not compulsory but provides stronger legal protection.
- The Geographical Indications Registry is located in Chennai and administers GI registrations.
- The initial registration is valid for 10 years and can be renewed indefinitely.

Importance of GI Protection

- Protects the reputation and distinctiveness of regional products.
- Prevents unauthorised use or misappropriation, which can cause economic harm and consumer deception.
- Promotes rural development through enhanced marketability of unique regional products.

Examples of famous Indian GIs include Darjeeling Tea and Basmati Rice, whose qualities and fame are rooted in their geographic origin.

06. PROTECTION OF UNDISCLOSED INFORMATION (TRADE SECRETS)

Trade secrets or undisclosed information refer to confidential business information that provides a competitive advantage because it is not generally known or readily accessible.

Characteristics of Trade Secrets

- The information is secret, meaning it is not publicly known within the relevant business circles. It has commercial value precisely because it remains secret.

- The owner has taken reasonable measures to maintain its secrecy.

Examples include formulas, methods, processes, patterns, compilations, and techniques.

Legal Status and Protection in India

- India does not currently have a dedicated statute exclusively for trade secrets.
- Protection is primarily provided under contract law (for example, confidentiality agreements) and common law principles.
- The Indian Contract Act, 1872, and certain provisions of the Indian Penal Code (Nyaya Sanhita), as well as the Information Technology Act, 2000, provide indirect protection.
- Recent developments include the proposed Protection of Trade Secrets Bill, 2024, which aims to establish a comprehensive legal framework addressing trade secret misappropriation, enforcement, and remedies.
- The Bill defines trade secrets precisely and introduces strong mechanisms for legal recourse in commercial courts, including injunctions and damages.

Protection of undisclosed information is critical for industries, research institutions, and businesses relying heavily on innovation and confidential know-how. Despite being less discussed than patents or copyrights, trade secret protection is often the most vital and practical form of intellectual property protection for many sectors.

Volume: 05 Issue No: 12

ECOLOGICAL RESTORATION OF DEGRADED LANDSCAPES: PRINCIPLES, DESIGN STRATEGIES, AND KEY HABITAT COMPONENTS

Article ID: AG-VO5-I12-53**Gowthaman Nagamuthu***

Landscape Designer and Consultant, JoyGreen Landscaping LLC, Dubai, UAE

*Corresponding Author Email ID: creativeglade@gmail.com

Abstract

Ecological restoration seeks to repair and revitalize degraded ecosystems so that they regain their ecological functions, biodiversity, and capacity for self-sustaining regeneration. This article outlines the conceptual basis of ecological restoration and describes key landscape components and design strategies that support resilient ecosystems, with a focus on riparian buffers, forest patch restoration, wildflower meadows for pollinators, wetlands dominated by reeds and aquatic plants, and nature-based visitor access through rustic trails and boardwalks. A guiding design philosophy of minimal artificial elements is emphasized to ensure that restored landscapes blend seamlessly with their natural context, while also providing opportunities for education, recreation, and long-term ecological stewardship.

Keywords: ecological restoration, riparian buffers, forest patch restoration, wildflower meadows, marshes, boardwalks, rustic trails, habitat design, nature-based solutions

Introduction

Ecological restoration is the intentional process of assisting the recovery of ecosystems that have been degraded, damaged, or destroyed. It aims to re-establish ecological structure, processes, and functions so that ecosystems become healthy, diverse, and self-sustaining over time. Typical goals include restoring native biodiversity, improving soil health, stabilizing hydrological regimes, enhancing wildlife habitat, and increasing resilience to climate change and human disturbance.

In designed landscapes—such as agricultural margins, urban fringes, river corridors, and post-industrial sites—restoration is not only an ecological intervention but also a design practice.

It mediates between human use and ecological integrity, creating spaces that are both aesthetically compelling and ecologically meaningful.

Concept and Approaches in Ecological Restoration

Ecological restoration typically combines two broad approaches: **passive restoration (natural regeneration)** and **active restoration**.

Passive Restoration (Natural Regeneration)

Passive restoration focuses on removing or reducing the drivers of degradation and allowing natural processes to recover the ecosystem. Key actions include:

- Excluding or limiting livestock and intensive human disturbance (e.g., fencing sensitive areas).
- Controlling invasive or non-native species that suppress native flora.
- Establishing buffer zones that reduce edge effects from adjacent land uses.

This approach is most effective where there is proximity to intact habitats and where viable seed banks and propagules persist in the soil. It is often low-cost and can be highly successful when ecological memory is still present.

Active Restoration

Active restoration intervenes more directly, particularly on highly degraded or cleared sites. Typical actions include:

- **Reforestation and replanting:** Introducing carefully selected native trees, shrubs, and groundcovers adapted to local soil, hydrology, and climate. Local seed sources are essential for genetic integrity.
- **Soil preparation and rehabilitation:** Reducing compaction, improving infiltration, and rebuilding organic matter through compost, mulching, and erosion-control techniques.
- **Invasive species management:** Mechanical and, where appropriate, controlled chemical removal of invasive plants prior to planting.
- **Use of nurse crops or pioneer species:** Establishing fast-growing native species that provide shade, shelter, and microclimate benefits for slower-growing climax species.
- **Hydrological restoration:** Reconnecting floodplains, re-shaping eroded channels, or introducing swales and depressions to restore groundwater dynamics.

Landscape-Level Strategy

Successful restoration projects consider the entire landscape, not just isolated sites:



- **Connectivity:** Creating ecological corridors, such as riparian strips or hedgerows, to link fragmented habitats and facilitate movement of species and genes.
- **Adaptive management:** Monitoring ecological and social outcomes and adjusting interventions in response to new information, disturbances, or changing climate.
- **Stakeholder engagement:** Involving local communities, landowners, and authorities to ensure long-term stewardship and align restoration with social and economic needs.

Key Components of Ecological Restoration Landscapes

Restored landscapes are mosaics of interrelated habitat types. The following components are particularly important for ecological function, biodiversity, and resilience.

Riparian Buffers Along Waterways

Riparian buffers are vegetated zones along rivers, streams, ponds, and wetlands that protect water quality, stabilize banks, and provide habitat. They often comprise three functional zones extending from the water's edge to upland areas:

Zone 1 (Stream Edge): Dominated by moisture-tolerant native trees and shrubs that stabilize banks, provide shade, and contribute organic matter to the watercourse.

- **Zone 2 (Middle Section):** A mix of trees and shrubs that slows runoff, facilitates infiltration, and absorbs nutrients and pollutants.
- **Zone 3 (Upland Edge):** Native grasses and wildflowers that further filter sediments and contaminants before they reach the inner zones.

Multi-layered plantings—canopy trees, understory shrubs, and herbaceous layers— enhance structural diversity, habitat complexity, and ecological function. These buffers improve water quality, reduce flood risk, and create continuous habitat corridors while also offering aesthetic and recreational value through trails and viewpoints.

Forest Patch Restoration



Forest patch restoration focuses on reviving small, fragmented woodlands embedded within agricultural or urban matrices. These patches function as critical “stepping stones” that support wildlife dispersal and genetic exchange.

A restored patch typically includes:

- **Multilayered vegetation structure:**
 - Canopy layer (tall native trees such as *Ficus*, *Terminalia*, *Acacia* or other regional forest species)
 - Understory layer of small trees and shade-tolerant shrubs
 - Herb and ground layers of ferns, native grasses, and shade-loving herbs
 - Leaf litter and mulch to promote nutrient cycling and soil biota
- **Habitat elements:**
 - Log and rock piles for reptiles, insects, fungi, and small mammals
 - Brushwood heaps and snags (standing deadwood) for cavity-nesting birds
 - Small ponds or ephemeral pools to support amphibians and invertebrates

- **Soil and hydrology restoration:**

- Application of organic compost and mulches
- Understory planting to reduce erosion
- Microtopography and swales that enhance infiltration and regulate runoff

Properly designed forest patches improve local microclimate, sequester carbon, contribute to groundwater recharge, and create opportunities for education and low- impact recreation. At a larger scale, they form part of Forest Landscape Restoration (FLR) strategies aimed at regaining ecological function and supporting human well- being.

However, small patches face notable challenges such as strong edge effects, limited funding and technical capacity, restricted seed sources, and, in some contexts, legal ambiguity regarding land classification. Addressing these constraints is essential for scaling up patch-based restoration

Wildflower Meadows for Pollinators



Wildflower meadows replicate natural grassland dynamics by combining native grasses with a diversity of flowering species that bloom from early spring to late autumn. They are critical habitats for pollinators and a key component of ecological restoration in parks, riparian edges, and urban open spaces.

Key characteristics include:

- High plant diversity with carefully selected native species.
- Seasonal succession of blooms that provide continuous nectar and pollen.

- Naturalistic, informal appearance with intermingled grasses and wildflowers.
- Habitat for nesting, overwintering, and larval development of insects.
- Low long-term maintenance and minimal chemical input once established.

Creation and management involve:

- Choosing sunny sites and reducing soil fertility to prevent dominance by coarse grasses.
- Thorough removal or suppression of existing vegetation.
- Sowing tailored native seed mixes that include annuals for first-year color, perennials for long-term structure, and native grasses for support and habitat.
- Implementing a mowing regime that supports establishment in year one and subsequently mimics traditional hay-cut systems, allowing seed drop while preventing nutrient accumulation.

When well designed, wildflower meadows significantly enhance pollinator diversity and abundance, contribute to climate resilience, and provide visual and educational value in restored landscapes.

Marshes and Reed-Dominated Wetlands



Wetlands dominated by reeds and other emergent herbaceous plants—such as cattails, sedges, and rushes—are typically classified as **marshes**.

Marshes are characterized by:

- **Dominant vegetation:** Non-woody, emergent hydrophytes like *Phragmites australis* (common reed), *Typha* spp. (cattails), and various sedges and rushes.
- **Hydrology:** Frequent or continuous shallow inundation, often with seasonally fluctuating water levels.
- **Soils and nutrients:** Fertile mineral soils with minimal peat accumulation and high nutrient availability, supporting high primary productivity.

Ecologically, marshes provide habitat for migratory birds, fish, amphibians, and invertebrates while also delivering crucial ecosystem services such as water filtration, nutrient retention, and flood attenuation. In restoration projects, re-establishing marsh hydrology and appropriate plant communities can dramatically enhance **landscape resilience** and biodiversity.

Visitor Access and Nature-Based Experience

Ecological restoration increasingly recognizes the importance of providing meaningful human access while safeguarding sensitive habitats. Two complementary strategies are the design of **rustic trails** and **elevated boardwalks**.



Rustic Trails

Rustic trails are informal paths constructed with compacted earth, gravel, woodchips, or simple stonework that follow the natural contours of the land. They offer a more immersive, rugged experience and are well-suited to stable terrains such as forests and dry slopes.

However, if poorly planned or maintained, rustic trails can contribute to soil erosion, compaction, and vegetation damage, especially where visitors stray off-path. They are generally less accessible to people with limited mobility but provide valuable opportunities for nature-based recreation and environmental education when carefully designed and managed.

Boardwalks and Elevated Walkways

Boardwalks are elevated structures—often timber or composite decks—that traverse wetlands, marshes, and other fragile habitats. They:

- Minimize physical disturbance by lifting foot traffic above sensitive soils and vegetation.
- Allow free movement of water and wildlife beneath the structure.
- Provide a stable, dry, and typically more accessible surface suitable for wheelchairs, strollers, and visitors of varied abilities.

Boardwalks, often combined with viewing platforms and interpretive signage, are powerful tools for balancing conservation with public access, enabling people to engage closely with restored ecosystems without compromising ecological integrity.

Design Philosophy: Minimal Artificial Elements

A unifying design philosophy in many restoration projects is the minimization of artificial elements so that built features appear as subtle extensions of the land. In such landscapes:



- Materials are predominantly natural—stone, timber, and soil in their raw or

- minimally processed forms.
- Structures are low-profile and organic, with gentle curves and irregular forms inspired by natural geometry rather than rigid, rectilinear lines.
 - Planting schemes rely on native species and naturalistic patterns that mirror wild ecosystems.
 - Pathways emulate animal trails; water features resemble springs, streams, or ponds rather than ornamental basins.
 - Seating, lookout points, or shelters are integrated into boulders, logs, or timber forms that visually and materially harmonize with their surroundings.
 - This approach helps create quiet, immersive environments where ecological processes and natural aesthetics take precedence, and where the presence of design is felt as a gentle guidance rather than a dominant imposition.

Challenges and Opportunities

Despite the clear ecological and social benefits, ecological restoration faces several challenges:

- **Edge effects in small patches:** Increased exposure to wind, light, and invasive species can reduce habitat quality for interior-dependent flora and fauna.
- **Resource limitations:** Many projects operate with constrained funding, limited technical expertise, and insufficient long-term maintenance capacity.
- **Seed and plant material supply:** Access to diverse, locally adapted native seeds and nursery stock is often a bottleneck.
- **Policy and legal frameworks:** In some jurisdictions, landowners may hesitate to restore tree cover due to uncertainty about future land-use rights or classification of restored areas.

At the same time, ecological restoration presents significant opportunities to:

- Rebuild biodiversity and ecosystem services in human-dominated landscapes.
- Create living laboratories and outdoor classrooms for environmental education.
- Enhance climate resilience through increased carbon sequestration, improved hydrology, and reduced urban heat.
- Foster collaborative stewardship across communities, landowners, and institutions.

Conclusion

Ecological restoration integrates science, design, and community involvement to transform degraded sites into functioning, biodiverse, and resilient ecosystems. By combining passive and active restoration strategies at a landscape scale and by carefully designing key habitat components—such as riparian buffers, forest patches, wildflower meadows, and marshes—practitioners can re-establish ecological processes while providing meaningful human access through rustic trails and boardwalks.

A design ethos of minimal artificial intervention ensures that restored landscapes feel authentic and ecologically grounded, allowing nature to lead while human presence remains subtle and respectful. As global pressures on ecosystems intensify, ecological restoration will continue to play a crucial role in safeguarding biodiversity, supporting ecosystem services, and reconnecting people with the natural world.

References

- Brancalion, P.H.S. & Holl, K.D., 2020. Guidance for successful forest landscape restoration. *Journal of Applied Ecology*, 57(6), pp.1107–1116.
- Dicks, L.V. et al., 2021. Guidelines for global pollinator restoration. UNEP & FAO.
- Holl, K.D., 2017. Restoring tropical forests. *Biotropica*, 49(6), pp.731–740.
- IPBES, 2019. Global Assessment Report on Biodiversity and Ecosystem Services. United Nations.
- Menz, M.H.M., Phillips, R.D. & Winfree, R., 2011. Pollinator-friendly habitat restoration. *Trends in Ecology & Evolution*, 26(10), pp.468–475.
- Mitsch, W.J. & Gosselink, J.G., 2015. *Wetlands*. 5th ed. Wiley.
- Naiman, R.J. & Décamps, H., 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics*, 28, pp.621–658.
- Palmer, M.A. et al., 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology*, 42(2), pp.208–217.
- Pywell, R.F. et al., 2011. Restoration of species-rich grasslands on arable land. *Journal of Applied Ecology*, 48(3), pp.503–513.
- Sweeney, B.W. & Newbold, J.D., 2014. Streamside forest buffer restoration. *Freshwater Science*, 33(1), pp.1–19.
- UN Environment Programme, 2021. UN Decade on Ecosystem Restoration Strategy.

ECONOMIC ASPECTS OF IPR

Article ID: AG-VO5-I12-54**¹Swaminathan, N., ^{1*}V. Krishnan*, ¹V. Ramesh, ²M. K. Sakthi Anand and ³J. Arathi**

¹Faculty, ²Ph. D. Scholar & ³PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, araikal 609603, U. T. of Puducherry, India

*Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Intellectual property rights (IPRs) serve as a key lever for fostering innovation, competitiveness, and economic growth in today's economies. In India, IP activity has reached unprecedented levels, reflecting both rising awareness and substantial policy advocacy. Between 2020-21 and 2024-25, India recorded a 44% increase in total IP filings, with Geographical Indications experiencing an extraordinary 380% rise, Designs up by 266%, Patents by 180%, and Copyrights by 83%. This surge signals both greater investment in creativity and the improved ability of firms and individuals to commercialize new ideas, contributing directly to economic resilience and industry dynamism.

Recent European studies offer more granular insights into the economic impact of IPRs. In 2025, a comprehensive report from the European Patent Office (EPO) and the EU Intellectual Property Office (EUIPO), analysing over 119,000 firms, found that small and medium-sized enterprises (SMEs) owning IPRs achieve 44% higher revenue per employee compared to non-owners, with the greatest gains for those leveraging bundles of patents, trademarks, and designs. This confirms earlier findings that active IPR management is a strong predictor of firm growth: SMEs with IP filings are 21% more likely to experience growth periods and 10% more likely to become high-growth firms. These results illustrate both the dynamic benefits—stimulating innovation and future growth—and the static trade-offs, where strong protection may temporarily reduce consumer access but ultimately enhances industry competitiveness and economic resilience.

STATIC AND DYNAMIC FAILURES IN MARKETS FOR INFORMATION

Static and dynamic failures in markets for information arise from the unique economic characteristics of information goods, which underpin intellectual property rights (IPR) policy debates.

Non-rivalry: One user's consumption does not reduce others' ability to use the same information, such as a patented invention, software, or brand name. The marginal cost of providing access to additional users is near zero, suggesting that wide access is socially optimal.

Non-excludability: Without legal means to exclude unauthorized use, free-riding occurs as others can copy valuable information easily. This reduces incentives for the original creators to invest in producing new intellectual property, threatening innovation.

THE TRADE-OFF BETWEEN STATIC AND DYNAMIC EFFICIENCY

IPR policy must balance conflicting goals:

Static efficiency demands broad dissemination of intellectual property at its marginal social cost to maximize access and consumer welfare.

Dynamic efficiency necessitates granting innovators exclusive rights to recoup high fixed R&D costs and maintain innovation incentives.

Too weak IPR protection leads to insufficient innovation, harming growth and culture. Overly strong protections restrict access and raise prices, generating deadweight loss. The policy trade-off is often modelled as balancing monopoly rents (necessary incentives) against lost consumer surplus caused by restricted access.

MARKET FAILURES AND POLICY IMPLICATIONS

IPRs impose costs including rent-seeking, duplicated R&D investment, litigation expenses, and transaction costs in licensing. Externalities from innovations, such as network effects and spillovers, mean the social value often exceeds private market returns, justifying public intervention and calibrated IPR policies.

Stronger IPRs positively influence innovation, domestic and foreign knowledge creation, and firm performance; firms owning IPRs show notably higher revenues per employee, especially SMEs (44% higher revenue per employee reported in 2025). However, excessive IPR strength can generate static distortions by limiting dissemination and access, potentially slowing incremental and spill-over innovations critical for broader economic growth.

The fundamental economic challenge in designing intellectual property rights lies in balancing two competing objectives: facilitating broad consumer access to new products at marginal cost, and providing sufficient incentives for innovation by allowing creators to recoup their investments through monopoly rents. The basic trade-off is illustrated in figure 1, which demonstrates a linear demand and marginal revenue for a product that has been invented and may be supplied to the market at constant marginal cost.

In a perfectly competitive market, optimal ex-post pricing dictates that the product should be sold at marginal cost, represented by point C in the figure. Pricing at this point maximizes consumer welfare by generating the consumer surplus area APCC. This scenario is static-efficient since it ensures users wide access at prices reflecting the true social cost of production. However, pricing at marginal cost leaves the innovator with **zero economic rents**, eliminating any possibility to recover the fixed costs of research and development (R & D). Without the prospect of compensation, firms lack incentives to undertake the costly investment required to create the product. Consequently, the product would remain undeveloped, and the entire potential surplus represented by APCC would be lost.

To resolve this market failure, society grants an intellectual property right such as a patent, effectively creating a **temporary monopoly**. This allows the innovator to set a higher price at point M. Through monopoly pricing, the firm obtains rents represented by area PMPCBM, which constitute a return on the initial investment and incentivize continued innovation.

Yet, monopoly pricing introduces inefficiencies. The imposition of a price above marginal cost restricts consumption, leading to a **deadweight loss**, marked as area MBC in the figure. This loss reflects the reduction in total surplus due to diminished access and reduced consumer welfare compared to the competitive scenario.

The analysis underscores the **fundamental trade-off in IPR policy**: firms require sufficient protection to encourage innovation, but such protection inherently restricts access and generates welfare losses. The optimal IPR regime must thus carefully balance these effects, providing enough monopoly power to stimulate invention while limiting inefficiencies imposed on consumers.

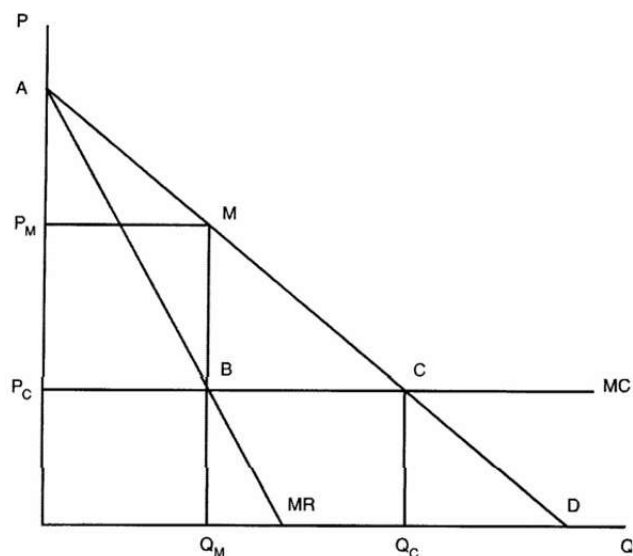


Fig. 1. Basic access innovation trade-off in IPRs

INTELLECTUAL PROPERTY RIGHTS IN AN OPEN ECONOMY

The conventional analysis of intellectual property rights (IPRs) largely considers a closed economy setting. However, in today's interconnected world of multiple countries linked through trade and investment, the dynamics of IPRs become substantially more complex.

Figure 4.1 highlights a fundamental consequence of IPR protection in an open economy: when a country imports or produces imitative products at competitive prices, granting IPR protection shifts monopoly rents to foreign rights holders. This transfer causes a static welfare loss due to worsened terms of trade and reduced output by unauthorized local producers. For smaller countries, this loss may outweigh any benefits if foreign firms are not incentivized to innovate products tailored to local demands. Such considerations underpin much resistance to stronger IPRs in developing countries.

When countries grant IPR protection for imported or imitated technologies, there is a transfer of monopoly rents to foreign rights holders, often exacerbating terms-of-trade losses for smaller economies. According to OECD (2023) report, developing countries with limited market influence experience static welfare losses amounting to approximately 2% to 5% of their GDP due to stronger intellectual property rights protection on imported goods, primarily resulting from restricted access and increased prices.

Conversely, inward foreign direct investment (FDI) inflows driven by stronger IPR regimes have risen substantially since 2018. UNCTAD (2024) notes a 12% annual average

increase in technology-related FDI in developing countries with improved IPR frameworks, reversing prior declines attributed to weak patent enforcement.

Developing countries often tolerate weaker IPR regimes as a form of **strategic trade policy**. Weak patents, trade secrets, and copyrights allow low-cost imitation and copying of foreign technology, effectively serving as a form of **uncompensated technology transfer**. This has historically justified reluctance to grant patents, balancing access with innovation incentives from producers.

However, weak IPRs also entail costs such as higher prices on imports, reduced competition in domestically imitative industries, job losses, and limited access to advanced external technologies.

Nonetheless, stronger IPR regimes in developing countries can foster **domestic innovation**, particularly when local markets are large and technological capabilities are significant. Trademarks have shown robust elasticity with product development, providing tangible incentives. Moreover, robust IPR protection attracts greater trade, inward foreign direct investment (FDI), and lowers contractual costs in licensing technology.

IPRs are national in scope, permitting significant cross-country differences in regimes, historically giving rise to trade conflicts. A notable example is the evolution of U.S. copyright law, which for centuries restricted protections for foreigners to foster domestic cultural industries and authorized parallel imports of foreign works. Changes only came with the International Copyright Act of 1891 and full non-discrimination with U.S. accession to the Berne Convention in 1989. This trajectory highlights how weaker protections often served as **infant-industry support** for emerging creative sectors.

Today, the sharpest differences in IPR protection remain along **North-South lines**, with innovative countries in the North criticizing many developing nations for:

- Poor enforcement of copyrights and trademarks facilitating piracy and counterfeiting.
- Exclusions or weaknesses in patent protection for pharmaceuticals, chemicals, and biotechnological inventions.
- Controversial practices regarding compulsory licensing and inadequate compensation.

Empirical analyses using firm-level data from emerging markets show that countries with expanded IPR protections experience a 5–8% annual increase in domestic patent filings and a measurable boost in R&D spending since 2019. Particularly, trademark registrations have surged

by over 10% per annum in developing economies, signalling responsiveness of product innovation sectors to legal incentives. The costs associated with licensing technologies have decreased by approximately 20% between 2018 and 2024 in countries adopting stronger IPR protections, facilitating broader diffusion of advanced technologies from the global North to South. This trend aligns with reduced contractual and enforcement risks reported by multinational corporations, which encourage investment and technology sharing. Despite these gains, enforcement gaps persist. A 2022 global intellectual property report reveals that over 40% of surveyed developing countries reported issues with counterfeit goods fuelling losses exceeding 5% of GDP, largely in pharmaceuticals and software sectors. Moreover, biotechnological patent protection remains contested, with significant variation in legal frameworks and reluctance to grant patents on genetically modified organisms across developing regions.

INTELLECTUAL PROPERTY RIGHTS AND ECONOMIC GROWTH

Technological progress is widely recognized as the principal driver of long-run economic growth. It arises from purposeful investments in research and development (R&D) aimed at creating new or improved products. Intellectual property rights (IPRs) play a crucial role by encouraging these investments and facilitating the dissemination of knowledge, which cumulatively enhances global innovation.

In a global context, the interaction between developed "North" countries and developing "South" countries highlights complex dynamics. The main concerns have been whether increased IPR protection in the South would increase (a) the rate of (global) growth, (b) the rate of technology transfer from the North to the South, and, (c) welfare levels in both locations. Stronger IPRs in the South tend to incentivize innovation in the North by expanding market opportunities, but the benefits to the South depend largely on its capacity for productive R&D and substantial market size. Excessively strong IPR protection can limit imitation that developing countries rely on, potentially reducing welfare if local innovation capacity is low.

Dynamic models further illustrate that while protection in the South can boost Northern innovation in the short term, it may reduce overall global growth in the long run due to resource competition effects. Foreign direct investment (FDI) moderates these effects by relocating production and innovation activities across borders.

IPR regimes also influence technology licensing, where stronger protections reduce enforcement costs, promote licensing agreements, and encourage further innovation. Empirical research using measures such as the Rapp-Rozek and Ginarte-Park indices consistently finds positive correlations

Table 1. Summary of Research on IPR and Growth

Study	Sample and period	Method	Dependent variable(s)	IPR Index Measure	Study focus/ Additional aspect	Key Result
Gould, Rapp and Rozek (1996)	95 countries, 1960–1988	Cross-sectional regression	Growth of real GDP per capita	Rapp and Rozek IPR Index	Examines IPR-growth link globally; checks effect modification by trade openness	Positive IPR impact on growth; stronger effects in open economies
Thompson and Rushing (1996)	112 countries, 1970–1985	Cross-sectional regression	Growth of real GDP per capita	Rapp and Rozek IPR Index	Tests effect heterogeneity by GDP per capita level	Positive effect only for countries above certain income threshold
Thompson and Rushing (1996)	55 countries, 1971–1990	Seemingly Unrelated Regressions	Total Factor Productivity (TFP)	Rapp and Rozek IPR Index	Links IPR protection to productivity components influencing growth	Positive impact on TFP and output growth in relatively rich countries
Park (1999)	60 countries, 1960–	Seemingly unrelated	Real GDP growth	Ginarte and Park Index	Decomposes direct and indirect	No direct growth impact; indirect positive

	1990	d regressi ons			growth effects through capital and R & D	impact via capital and R & D investment
Falvey <i>et al.</i> (2006)	80 countrie s, 1975– 1994	Thresho ld regressi on	Economic growth rate	Various IPR indices	Explores nonlinear relationships; distinguishes income groups	Positive effects in rich countries; mixed/negative in middle- income countries
Kwan and Lai (2003)	U.S. data, dynamic model	Calibrat ed general equilibri um	Welfare, R&D investment	Patent breadth and length	Microscopic model analysing trade-offs between protection breadth and welfare	Indicates optimal patent scope balancing innovation incentives and consumer access
Branstetter <i>et al.</i> (2006)	50+ countrie s, 1980s- 2000s	Differen ce-in- differen ces	Patent filings, innovation	TRIPS Agreeme nt impleme ntation	Assesses impact of international patent reforms on innovation outputs	TRIPS compliance increased patenting where local capabilities existed
Maskus and Merriman (2017)	30+ countrie s	Instrum ental variable s	Innovation, foreign direct investment	Patent rights indices	Examines relationship of IPRs with FDI inflows	Strong IPRs attract FDI and facilitate knowledge

			(FDI)		and domestic innovation	spillovers enhancing growth
Viglioni (2023)	Cross-country, recent	Meta-analysis & literature review	Innovation activity, growth	Composite IPR strength indexes	Synthesizes evidence linking IPR strength and innovation	Stronger IPRs boost domestic and foreign innovation and economic growth
Guo (2025)	Panel data, 2000–2023	Economic panel analysis	Economic growth, productivity	Patent protection indices	Focus on quality productivity and innovation output	Quality-adjusted productivity significantly raised by stronger IPRs

CONSTRUCTING AN IPR SCORE

In early empirical efforts aimed at quantifying the strength of national intellectual property rights (IPR) regimes, Ferrantino (1993) employed a simplified dummy variable approach. His variables captured whether countries were members of major international agreements such as the Paris, Berne, and UPOV Conventions, along with the patent protection term duration. Surprisingly, his findings emphasized that **only the duration of patent protection** significantly explained differences in economic activity across countries at that time. This outcome was partially due to limited variation—most countries were already party to broad agreements like the Paris Convention—thus constraining explanatory power.

TWO MAIN APPROACHES TO CONSTRUCTING IPR INDICES

IPR indices typically adopt one of two methodologies:

- 1. Legislation-Based Approach (Text Analysis):** This approach systematically reviews national intellectual property legislation by codifying legal provisions into quantitative scores. Examples include the seminal works:

- **Rapp and Rozek Index (1990):** Focuses on minimum standards of patent law adherence based on the U.S. Chamber of Commerce’s guidelines. It scores countries on a 6-point scale emphasizing laws “in force” against infringement rather than their enforcement or implementation.
- **Ginarte and Park Index (1997):** Advances the legislative approach by scoring five critical components on a 6-point scale. This is constructed quinquennially (every five years) from 1960 to 1990, permitting analysis of temporal trends and policy changes. Despite its detail, the index is noted for a strong positive correlation with national GDP per capita, partly reflecting that richer nations tend to adopt stronger patent protections.
 - Extent of coverage (e.g., pharmaceuticals, food, plant varieties)
 - Membership in international agreements (e.g., Paris Convention, Patent Cooperation Treaty, UPOV)
 - Measures mitigating loss of protection (e.g., compulsory licensing, revocation)

Table 2. Ginarte and Park Index components

Components	Description	Scoring (Yes=1, 0 if No)
Patentability of pharmaceuticals	Protection extended to drugs and medical products	1 if yes, 0 if no
Patentability of chemicals	Protection for chemical compounds	1 if yes, 0 if no
Patentability of food	Patentability of food-related inventions	1 if yes, 0 if no
Patentability of plant and animal varieties	Protection for biological variants	1 if yes, 0 if no
Patentability of surgical products	Covering medical devices	1 if yes, 0 if no
Patentability of microorganisms	Protection for microorganisms	1 if yes, 0 if no
Patentability of utility models	Protection for small-scale	1 if yes, 0 if no

	inventions	
Membership in international treaties	Membership in conventions like Paris, PCT, UPOV	1 if yes, 0 if no for each
Loss of protection mitigation measures	Working requirements, compulsory licensing, etc.	1 if yes, 0 if no
Enforcement mechanisms	Injunctions, contributory infringement, burden-of-proof reversal	1 if yes, 0 if no
Duration of patent protection	20 years standard (1), prorated if less than 20	Continuous between 0 and 1

- Enforcement provisions (e.g., availability of preliminary injunctions, burden-of-proof rules)
- Duration of patent protection (standard 20 years)

2. Survey-Based or Judgment-Based Approach: Instead of relying solely on legal texts, this method uses informed subjective assessments or surveys of legal practitioners, multinational firm managers, or IP specialists regarding the effectiveness of IPR regimes, including enforcement quality.

Sherwood's Index (1997): Applies a comprehensive scoring system across nine components (e.g., enforceability, administration, copyrights, patents, trademarks, trade secrets, treatment of life forms, treaty adherence, and general public commitment). It is based on qualitative interviews and expert judgments in 18 developing countries. While detailed, it carries certain arbitrariness in component weighting and subjective scoring.

CHALLENGES AND CONSIDERATIONS IN MEASURING IPR STRENGTH

- While the legislative approach reflects the existence and content of patent laws, it may understate enforcement realities, especially in developing countries where laws exist but enforcement capacity is weak. Post-TRIPS (1995), enforcement has become a more important determinant, though difficult to quantify consistently.
- Survey-based measures capture perceptions of IPR effectiveness and enforcement but risk endogeneity and are influenced by market conditions and respondents' biases.

- The low correlation between the Rapp and Rozek and Ginarte and Park indices ($r \approx 0.235$) highlights differences in measurement methodology and scope. In contrast, the Ginarte and Park index's

Table. 3. Modern composite framework for Assessing IPRs Protection

Components	Subcomponents/ Indicators	Weight (%)	Description
1. Legal Coverage and Scope	Patentability across critical sectors (pharmaceuticals, biotechnology, software, plant varieties); Trademark and Copyright coverage	25	Measures the breadth and inclusiveness of IP protection across innovation-sensitive sectors.
2. International Commitments	Membership in TRIPS, Paris Convention, Berne Convention, Patent Cooperation Treaty (PCT), UPOV	10	Reflects adherence to key international agreements ensuring minimum standards and cooperation.
3. Enforcement Mechanisms	Judicial effectiveness, availability of injunctions, border controls, IP administrative agencies, infringement penalties	25	Captures the robustness and efficacy of IP law enforcement, crucial for deterrence and protection.
4. Duration and Formalities	Statutory protection durations (patents ≥ 20 years, trademarks, copyrights), renewal/maintenance	10	Accounts for length and formal conditions affecting IPR sustainability and market confidence.

	requirements		
5. Flexibilities and Safeguards	Provisions for compulsory licensing, research and education exceptions, fair use, parallel imports	10	Measures balance between rights holders' protections and public interest or developmental needs.
6. Commercialization Support	Existence of technology transfer offices, IP valuation/licensing frameworks, innovation grants, startup incentives	10	Reflects institutional mechanisms facilitating effective commercialization and practical use of IP.
7. Transparency & Accessibility	Availability of laws/regulations online, ease and cost of IP filing, registration speed, enforcement accessibility	10	Assesses administrative transparency, procedural efficiency, and user-friendliness for IP actors.

- stronger correlation with economic output indicates that patent law strength is intertwined with a country's development level.
- An observed empirical pattern, often called the U-shaped curve of IPR strength and income, shows that countries may initially weaken IPRs as incomes begin to rise, to support infant industries and technology absorption, before strengthening them further at higher income levels to sustain innovation incentives.

In light of recent developments and the evolving complexities of intellectual property rights (IPRs), a robust composite scoring framework is essential for accurately assessing the strength of IPR protection across countries. The following modern framework integrates key components reflecting contemporary policy priorities, legal developments, enforcement

realities, and commercialization support, as informed by recent scholarship and global practice insights (OECD, 2025; WIPO, 2023; McKinsey Global Institute, 2025).

SCORING METHODOLOGY

Each subcomponent is quantitatively scored using normalized scales (e.g., 0–100) derived from comprehensive qualitative and quantitative data sources, including legislative text analyses, practitioner surveys, enforcement records, and judicial effectiveness metrics. The overall IPR strength score is computed as a weighted sum, ranging from 0 (weakest protection) to 100 (strongest protection).

The weighting scheme prioritizes legal coverage and enforcement (50%) to reflect their paramount importance in conferring effective protection. Simultaneously, the framework incorporates balance and public interest **flexibilities** (20%) to ensure equitable and sustainable IP regimes. The remaining 30% is allocated to international cooperation, commercialization support, and transparency, recognizing their critical roles in fostering innovation ecosystems and accessible IP regimes in globalized markets. Dynamic weighting adjustments allow tailoring the framework to country-specific contexts or research emphases, embracing heterogeneity in stage of development, sectoral composition, and governance quality.

Volume: 05 Issue No: 12

FISHING BEYOND LIMITS: UNDERSTANDING THE ECOLOGICAL AND ECONOMIC CONSEQUENCES OF OVERCAPACITY

Article ID: AG-VO5-I12-55***Akash Arul. A¹ and F. Rose Ruby²**

UG Students, College of Fisheries Science, St. Devasahayam Institute of Fisheries Science & Technology, Amanattantheri, Kanniyakumari, Tamil Nadu - 629 193, India

*Corresponding Author Email ID: aakashdifst@gmail.com

Abstract

Global marine capture fisheries production, exceeding 80 million metric tons annually, has plateaued and slightly decreased due to overexploitation. According to the FAO, only 23% of assessed marine fisheries are underexploited or moderately exploited, while 77% fall into categories indicating full exploitation or worse. A study by Costello et al. found that 64% of unassessed fish stocks are overfished. The trend toward stock depletion raises significant concerns over global overfishing and resultant overcapacity in fishing fleets, particularly in wealthier high-latitude regions. Fishing capacity, defined as the maximum output a fleet can achieve given optimal resource condition, varies between concepts of excess capacity and overcapacity. While excess capacity may arise temporarily, overcapacity results when the number of vessels exceeds the maximum sustainable yield (MSY), leading to serious sustainability issues. The impact manifests in stock depletion and fishing inefficiencies. Over the past 25 years, the fishing fleet in India has expanded from 18,790 mechanized boats in 1980 to 58,911 in 2005, resulting in significant overcapacity due to advances in technology. Overall, overcapacity continues to pose substantial challenges to both domestic and high-seas fisheries, necessitating comprehensive policy responses and international cooperation.

Key Words: Marine resources, Mechanization, Open access, Overcapacity, Overexploitation, Subsidies, Maximum Sustainable Yield (MSY), Economic and Food Needs, IUU Fishing, Fleet.

Introduction

With an annual production of over 80,000,000 MT, global marine capture fisheries production has plateaued and slightly decreased in recent years (FAO 2012). The majority feel this is because human harvesting capability has now surpassed the world's oceans' ability to produce responsibly. According to FAO (2013), only 23% of the 600 marine fisheries worldwide with stock assessments are classified as 77% are totally exploited, overexploited, exhausted, or recovering from depletion, and the remaining 77% are either underexploited or moderately exploited. Nonetheless, the vast majority of fish populations around the world are unstudied. Costello et al. (2012) investigated the status of marine fish stocks in locations where no official assessments had taken place and discovered that 18% of unassessed stocks had failed and 64% of unassessed fisheries were overfished. Overfishing and overcapitalization are typical in fisheries that have recently reached the harvest threshold of fully exploited or overexploited.

Fisheries that have recovered or are recovering and have already decreased harvest levels to the point that overfishing and overcapitalization are no longer problems are exempt from this criterion. Both of these global ratings exhibit comparable trends. Over the last few decades, more stocks have been revealed to be completely or excessively exploited, whereas fewer have been discovered to be underutilized. This issue of stock depletion points to a global problem of overfishing, which leads to a major overcapacity in the world's fishing fleets. Even if the overall trend appears to be in the wrong direction, there are numerous examples of ways to deal with or avoid overfishing and overcapitalization, particularly in wealthy, high-latitude countries.

What is Overcapacity?

Fishing Capacity

"The number of fish or fishing effort that can be produced over a period of time (such as a fishing season or year) by a vessel or fleet if fully utilised and for a given resource condition" is the definition of fishing capacity (FAO 2004). Additionally, this notion takes into account both input (like the number of days fished) and output (like economic efficiency) perspectives.

Excess Capacity

A short-term phenomenon known as excess capacity happens when a company produces less than it could normally. Operating conditions due to changes in market conditions such as input costs, output prices, or fish stock abundance. Overcapacity is not the same as excess capacity, which is a temporary issue. In this case, a certain amount of extra capacity is needed

during the rebuilding phase in order to harvest at the intended optimum yields later on when complete capacity utilization takes place. In environments like upwelling systems that generate copious amounts of small pelagic, fish stocks can fluctuate greatly from year to year. The fishing fleet may have extra capacity that is underutilized in lean years when the upwelling system produces less biomass since the biomass can be gathered quickly. The fleet's size and power may be insufficient to gather all of the biomass available in a given year or season during peak years. When there is continually excess capacity from year to year or season to season, an overcapacity problem occurs.

Overcapacity

Overcapacity is a long-run phenomenon that occurs when the potential output differs from a target level of production in the fishery, such as maximum economic output. The ability of a fleet to fish at levels over the sustainable catch level in a fishery (for example, because of an excess of vessels and/or fishermen) is referred to as overcapacity. The FAO has issued a warning that overcapacity frequently leads to overfishing and IUU. Throughout the negotiations, WTO members are debating whether and how to punish subsidies that result in overcapacity as well as how to recognize these subsidies. Every year, 300,000 dolphins and porpoises perish, 40 tons of coral are damaged in the Pacific Ocean, and There are 100 million sharks caught. Up to 90% of the huge fish in the Atlantic Ocean have been fished out, and more than 80% of shark species have vanished.

Comparison Between Excess-capacity and Over-capacity

Comparison	Excess-capacity	Over-capacity
Time Scale	Short-term issue	Long-term issue
Cause / Indicator	Occurs when production > sustainable yield temporarily	Occurs when number of vessels exceed MSY (Maximum Sustainable Yield)
Fleet Condition	Fleet may be optimal for a certain period	Fleet size continues to grow even after reaching MSY
Fishery Type / Nature	Common in seasonal fisheries	Occurs when fleet size is not controlled by capacity management
Market	Can be affected by market price	Less related to market; more related

Influence	fluctuations	to biological and fleet expansion issues
Impact on Catch	Excess capacity does not always mean overfishing	Catch levels decline after reaching MSY
Relationship to Sustainability	Not necessarily harmful if temporary	Harmful-leads to stock depletion and inefficiency
Management Implication	May not require major intervention if short-term	Requires strict capacity management to reduce fleet sizess

Overcapacity in Indian Fisheries: A Consequence of Technological Growth

Over the past 25 years, fishing fleets have become more numerous and more efficient. There were 58,911 mechanized boats in 2005, up from 18,790 in 1980, following the start of mechanization in the mid-1960s (CMFRI, 2006). Boat efficiency increased due to a number of factors, including sea endurance, engine power, and boat size. Traditional boats were first motorized in the middle of the 1980s, and they rapidly became popular. In 2005, there were 58,911 motorized boats and 75,591 non-powered boats. After motorization, the small craft had significantly greater mobility. These developments have led to the expansion of fishing into new regions and deeper waters.

Overcapacity is currently plaguing both the capital-intensive mechanized fishing business and the employment-oriented motorized sector. According to the United Nations Food and Agriculture Organization (FAO), fishing capacity is the quantity of fish that a vessel or fleet can catch in a certain amount of time (such as a year or a fishing season) provided it is fully utilized for a particular stock. The maximum harvest level that a fleet might achieve with specific input levels, such as fuel, fishing gear, ice, bait, engine power, and vessel size, would surpass the intended level of harvesting, which is referred to as "overcapacity." In other words, fleets that are overcapacity can capture more fish than are available.

Overcapacity in Global Fisheries: Trends, Challenges, and International Response

Low economic performance, illegal, unregulated, and unreported (IUU) fishing, and political pressure to establish catch limits above scientific recommendations are all consequences of overcapacity. It creates a vicious cycle that results in a growing disparity between fleet

capacity and available resources. Overcapacity and excessive fishing capacity impact numerous domestic fisheries worldwide, as well as several high-seas fisheries in an even more widespread form. After ten years of extremely intensive fleet development, overcapacity in global marine fisheries seems to be a comparatively recent phenomena, having emerged in the late 1980s. Nominal fleet size appears to have peaked in the middle of the 1990s, according to FAO data. However, as technology advances and older vessels are refitted, actual fishing capacity can still be growing. The FAO Committee on Fisheries (COFI) suggested in 1997 that FAO hold a technical consultation to address concerns about overcapacity in fisheries and develop guidelines.

Economic Costs and Policy Responses to Overcapacity in Fisheries

The harvesting process also incurs additional expenditures due to overcapacity. A longer-term issue, overcapacity is caused by a discrepancy between the resources required to harvest the resource at its "optimal" level and the resources used to do so. Regarding the necessity of getting rid of subsidies that lead to overcapacity, the international fishing community has taken definite stances and made pledges in international instruments and forums. The UN's 2002 WSSD Declaration called for the "elimination of subsidies that contribute to over-capacity." The FAO Committee of Fisheries (2005) decided in its twenty-sixth session to phase out subsidies that encouraged fleet expansion,

Causes of Overcapacity

Overcapacity

Many fishing enterprises across the world have massive vessels, equipment, and technology that they may use to reach deep into the ocean.

Unsustainable Fishing

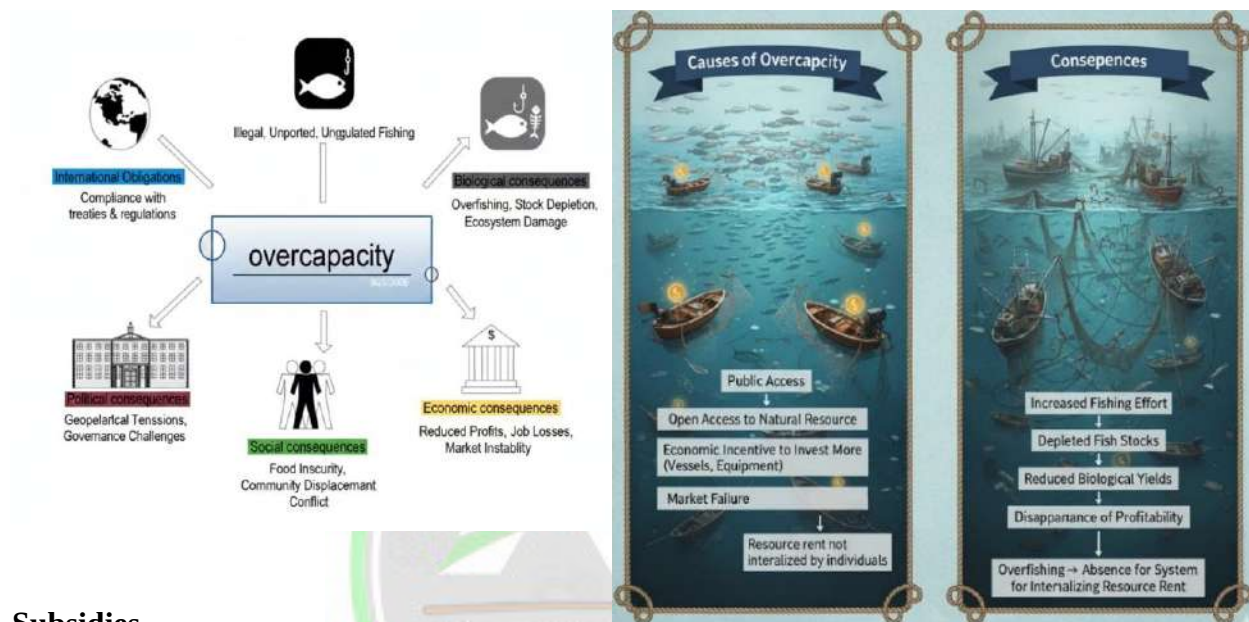
Unsustainable Fishing equipment, such as nets, can lead to overfishing and endangered species. It also entails catching sea creatures other than fish in the process.

Economic and Food Needs

The number of fish brought ashore by fishing industries is determined by the market and consumer demand. Humans have increased dramatically during the last century, as has the demand for food and seafood.

Public Access

Overcapacity in fisheries is generally viewed as an open access issue, as opposed to a lack of property rights or regulated access. This is the famous conclusion to Hardin's (1968) tragedy of the commons. This is an instance of market failure. To catch more fish and make more money, everyone has an economic incentive to invest more in fishing vessels, equipment, or engine horsepower.



Subsidies

Additionally, by attracting more fishermen to the fishery, cutting total fishing costs, and pushing the open access equilibrium farther down the yield curve, subsidies contribute to overcapacity. Policies that promote increased labour and the acquisition of fishing gear only contribute to the decline in catches. In open access situations where catches and profits drop, subsidies are often employed with the best of intentions, either to increase investment in fishing in areas where fish stocks were deemed to be underutilized or to increase fishermen's incomes.

Conclusion

Global marine capture fisheries production has stabilized with over 80 million MT annually but shows signs of depletion mainly due to overfishing, where 77% of assessed fisheries are fully exploited or worse. Many fish populations remain unstudied, with a significant fraction of unassessed stocks already overfished. Overcapacity occurs when the fishing fleet can fish above sustainable levels, resulting from an increase in fleet size and efficiency, leading to issues like illegal fishing and economic pressures to exceed scientific catch limits. Factors contributing to overcapacity include technological advancements, excessive harvesting

capabilities, and unsustainable fishing practices. The FAO has called for action to address these challenges, emphasizing the need to eliminate subsidies that encourage overcapacity in fisheries.

Reference

- Csirke, J., & Garcia, S. M. (2009). *Marine fishery resources, global state*.
<https://doi.org/10.1016/B978-012374473-9.00747-5>
- Mahon, R., Murphy, F., Murray, P., Rennie, J., & Willoughby, S. (1990). *Temporal variability of catch and effort in pelagic fisheries in Barbados, Grenada, St. Lucia and St. Vincent: With particular reference to the problem of low catches in 1989* (FI: TCP/RLA/8963 Field Document 2). FAO.
- Garcia, S., & Doulman, D. (2005). FAO's fisheries programme and the plan of implementation of the World Summit on Sustainable Development. In *Fisheries and the environment* (pp. –). https://doi.org/10.1007/1-4020-3133-5_11
- Squires, D., Kirkley, J., Joseph, J., Groves, T., & Reid, C. (n.d.). *Relating estimates of fishing capacity obtained from data envelopment analysis to traditional measures of fishing capacity*.

INDIAN LEGISLATION FOR IPR

Article ID: AG-VO5-I12-56**¹Ramesh, V.,^{1*}V. Krishnan, ¹N. Swaminathan, ²M. K. Sakthi Anand and ³J. Arathi**

¹Faculty, ²Ph. D. Scholar & ³PG Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India
Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Intellectual Property Rights (IPR) form a vital foundation for innovation, economic progress, and the protection of creative endeavours in India. As the nation's economy continues to expand and diversify, establishing a robust IPR framework has become essential for supporting inventors, authors, entrepreneurs, and communities. Various Indian statutes govern the realm of intellectual property, ensuring a systematic legal ecosystem that recognises and protects inventions, literary works, artistic creations, industrial designs, trademarks, plant varieties, and geographical indications. In India, the IPR framework has progressively evolved, responding both to domestic priorities and international obligations. The system is deeply influenced by the World Trade Organisation (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), which India ratified in 1995. Today, India has a comprehensive set of IPR laws covering patents, copyrights, trademarks, designs, geographical indications, plant varieties, and other emerging forms of intellectual property.

CONSTITUTIONAL AND JUDICIAL BASIS FOR IPR IN INDIA

The authority to legislate on intellectual property matters in India lies with the central government, as mandated by Entry 49 of List I (Union List) of the Seventh Schedule of the Constitution. This constitutional backing is complemented by critical fundamental rights, such as Article 19(1)(g), supporting economic activities, and Article 300A, upholding the property rights of individuals and entities. Indian courts have been instrumental in interpreting IPR provisions, ensuring that the enforcement of intellectual property does not hinder public interest. For

instance, recent judgments have focused on compulsory licensing in pharmaceuticals, allowing generic manufacturers to supply essential medicines, thereby ensuring affordable healthcare.

CONSTITUTIONAL FOUNDATION

- **Entry 49 of List I (Union List):** Seventh Schedule of the Indian Constitution empowers the Union Government to legislate on matters of patents, copyrights, trademarks, and industrial designs.
- **Article 19(1)(g):** Grants citizens the right to practice any profession or carry on any trade or business, indirectly encouraging the protection of intellectual works.
- **Article 300A:** Recognises the right to property, which extends to intellectual creations.

JUDICIAL ROLE

The Indian judiciary has played a proactive role in interpreting IPR law, ensuring a balance between private rights and public welfare. Landmark rulings have clarified principles relating to compulsory licensing, protection of traditional knowledge, and access to medicines.

PATENTS: LAW, GROWTH, AND RECENT CASES

The Indian Patents Act of 1970, amended multiple times to align with global standards, especially after joining the WTO-TRIPS framework, grants inventors exclusive rights for up to 20 years over novel inventions in any technological field. The explosive growth in the national innovation landscape is evident from recent statistics: Indian patent applications rose from 24,326 in 2020–21 to over 68,000 in 2024–25, marking over 180% growth. Notably, in 2025, the Controller General of Patents, Designs & Trademarks awarded a significant number of patents to domestic startups, such as those developing sustainable packaging solutions and novel diagnostic devices, signifying a shift towards indigenous innovation. Still, a major challenge remains: although filings have soared, commercialisation and technology transfer rates need improvement to match global benchmarks.

COPYRIGHT: PROTECTION OF CREATIVE WORKS

The Copyright Act, 1957, amended in 2012 and currently under additional review, protects original literary, musical, dramatic, and artistic works, as well as software and cinematographic films. Protection lasts for the life of the author plus 60 years. Recent legal amendments and court rulings have addressed the complexities of digital content and streaming, emphasising the importance of anti-piracy measures, digital rights management, and protection for creators against online infringement. Notably, the 2024 landmark case of Communication

Component Antenna (CCA) v. NASDAQ-listed infringers resulted in damages exceeding INR 217 crores for unauthorised use and reproduction of artistic works, signalling robust judicial support for rights holders.

TRADEMARKS: BRAND IDENTITY AND MARKET INTEGRITY

Trademarks, governed by the Trade Marks Act, 1999, are crucial for identifying and protecting brands, goods, and services. Registrations are granted for ten years and may be renewed indefinitely. India recorded approximately 538,000 trademark applications in 2024 to 2025 - a notable 28% increase from previous years, demonstrating growing brand consciousness among enterprises. In 2024, the Delhi High Court's decision in Kabushiki Kaisha Toshiba v. Toshiba Appliances reinforced trademark protection by affirming that similar-sounding brands cannot exploit established reputations. Companies like Sporta Technologies (Dream11) and Yamaha have successfully won legal protection and a permanent injunction for their marks, thereby strengthening the legal framework for brand owners and creating a safer commercial environment for consumers.

INDUSTRIAL DESIGNS: AESTHETIC INNOVATION

Industrial designs, protected under the Designs Act, 2000 for an initial term of ten years (extendable to fifteen), focus on the appearance, shape, and configuration of products. India witnessed a 266% surge in design applications over the last five years, largely fuelled by the success of domestic industries in textiles, packaging, and medical equipment. Recent examples include the registration and protection of innovative vaccine vial designs developed by Indian manufacturers during the COVID-19 pandemic, which not only prevented counterfeiting but also contributed to better supply chain management worldwide.

GEOGRAPHICAL INDICATIONS: PROTECTING UNIQUE REGIONAL IDENTITIES

The Geographical Indications of Goods (Registration and Protection) Act, 1999, recognises products with specific regional origins, such as Darjeeling Tea, Mysore Silk, and Kanchipuram Silk. Over the last five years, GI filings climbed from 57 to 274, highlighting increased awareness among farming and artisan communities. Recent GI registrations have included products like Araku Valley Coffee and Changthangi Pashmina, ensuring that producer communities receive recognition and economic benefit from their traditional skills and regional specialities.

AGRICULTURAL AND BIOLOGICAL INNOVATION: PLANT VARIETIES AND BIOPIRACY

The Protection of Plant Varieties and Farmers' Rights (PPVFR) Act, 2001, offers breeders exclusive rights over new plant varieties but preserves the rights of Indian farmers to save, use, exchange, and sell farm-saved seeds—a unique safeguard balancing innovation and food security. In recent years, India has seen the successful registration of several rice and wheat varieties, significantly boosting crop productivity and climate resilience. Parallel to these developments, the Biological Diversity Act, 2002, aims to prevent biopiracy and ensure fair benefit-sharing from biological resources, with high-profile enforcement cases involving neem, turmeric, and basmati rice that reinforce India's commitment to traditional knowledge protection.

SEMICONDUCTOR INTEGRATED CIRCUITS: FOSTERING A TECH-DRIVEN ECONOMY

With India's recent focus on electronics and semiconductor manufacturing, the Semiconductor Integrated Circuits Layout-Design Act, 2000, has gained renewed importance. Legal protection for microchip layout designs is now a central feature of the government's "Make in India" and "Digital India" initiatives. Indian tech firms, encouraged by supportive policies, have recently reported several successful registrations of new chip designs for use in consumer electronics and renewable energy devices, positioning India as a significant player in the global electronics supply chain.

ENFORCEMENT, ADJUDICATION, AND ADMINISTRATION OF IPR

Enforcement of IPR involves a complex interplay of civil, criminal, and administrative mechanisms. Civil courts frequently issue injunctions, damages, and account-for-profit orders, while criminal provisions enable fines and imprisonment in egregious cases, such as large-scale counterfeiting. Customs authorities, under the Customs Act, 1962, have seized record volumes of counterfeit electronic goods, pharmaceuticals, and branded apparel at borders in 2025, demonstrating a firm stance against cross-border IPR violations. Administration and registration of most IPRs fall under the Controller General of Patents, Designs & Trademarks, while specialised agencies manage plant varieties and biodiversity.

ENFORCEMENT OF IPR IN INDIA

Effective enforcement mechanisms are critical for ensuring IPR protection:

- **Civil Remedies:** Injunctions to prevent infringement, award of damages, delivery or destruction of infringing goods.
- **Criminal Remedies:** Imprisonment and fines against counterfeiters and pirates.
- **Administrative Measures:** Under the Customs Act, 1962, customs authorities can seize infringing goods at borders to prevent illegal import/export.

Table 3.1. Major IPR Legislations in India

Form of IPR	Legislation	Key Features	Duration
1. Patents	The Patents Act, 1970 (amended 1999, 2002, 2005)	Protects new inventions in any field of technology; excludes traditional knowledge, agriculture, and medical treatments; recognises product patents (post-2005). E.g., Pharmaceuticals, Biotechnological innovations.	20 years
2. Copyrights	Copyright Act, 1957 (amended 2012)	Covers literary, dramatic, musical, and artistic works; includes performers' rights and digital rights management. E. g., Books, Films, software.	Author's life + 60 years
3. Trademarks	Trade Marks Act, 1999	Protects brand identities; recognises service marks, well-known marks; allows renewal. E. g., TATA, Amul	10 years (renewable)
4. Industrial Designs	Designs Act, 2000	Safeguards novel aesthetic features of industrial products. Examples: Textile	10 years (+5 years extension)

		patterns, packaging	
6. Geographical Indications (GIs)	GI of Goods (Registration and Protection) Act, 1999	Protects goods with unique geographical origins; supports local producers. E. g., Darjeeling tea, Basmati Rice, Kanchipuram silk	10 years (renewable)
7. Plant Varieties & Farmers' Rights	PPVFR Act, 2001	Protects plant breeders' rights while safeguarding farmers' rights to save, exchange, and reuse seeds. E.g., Improved wheat and Rice varieties	Up to 15 –18 years (crop-specific)
8. Semiconductor Integrated Circuits Layout	SICLD Act, 2000	Grant exclusive rights over circuit layouts used in electronics. E. g., Microchip design	10 years
9. Biological Resources & Traditional Knowledge	Biological Diversity Act, 2002	Regulates access to genetic/biological resources; ensures equitable benefit sharing. E. g., Neen, Turmeric (Preventing biopiracy)	—

INDIA'S INTERNATIONAL COMMITMENTS

India is actively engaged in the global IPR regime that are

- Member of WTO (TRIPS Agreement, 1995).
- WIPO (World Intellectual Property Organisation) and signatory to key treaties such as: Paris Convention (industrial property protection); Berne Convention (copyright protection) and Budapest Treaty (recognition of microbial deposits for patents)

- India's amendments to the Patents Act (2005) particularly demonstrate its effort to align with TRIPS while safeguarding public health and farmers' rights through provisions like compulsory licensing.

CHALLENGES IN IMPLEMENTATION

Despite a strong legal structure, several challenges hinder the effectiveness of IPR laws in India

- **Patent pendency:** Significant delays in examination and grant of patents.
- **Awareness gaps:** Limited knowledge among rural artisans, small-scale industries, and farmer communities.
- **Piracy and counterfeiting:** Rampant violation in music, films, software, and branded goods.
- **Social concerns:** Conflict between incentivizing innovation and ensuring affordable access to healthcare, education, and seeds.

RECENT ADVANCES, DIGITAL TRANSFORMATION, AND ONGOING CHALLENGES

India's intellectual property environment has entered a new era of modernisation, characterised by the introduction of the National IPR Policy (2016), large-scale digitalisation of IP offices, and the establishment of IP facilitation centres for startups and MSMEs. The last two years have seen further momentum, with the introduction of a draft Copyright (Amendment) Rules, 2025, to digitise copyright licensing, government consultations on regulating artificial intelligence, and the strengthening of the Traditional Knowledge Digital Library (TKDL). In July 2024, a private member's bill was tabled in Parliament, advocating for an Artificial Intelligence Regulatory Authority, emphasising the need for legal adaptation to fast-evolving technologies.

Despite these advances, India continues to grapple with delays in patent examination, lower commercialisation rates, a persistent IP literacy gap among grassroots innovators, and persistent digital and physical piracy. Notably, international reports such as the US Special 301 Report 2025 highlighted both India's improvements and ongoing enforcement challenges, particularly in relation to pharmaceuticals and digital content.

CONCLUSION: TOWARD A RESILIENT IPR REGIME

The trajectory of intellectual property rights in India reflects both remarkable progress and clear areas for growth. The continuous rise in IPR filings, expanding legal coverage, notable



court decisions, and real-world examples of innovation protection signal the country's commitment to a knowledge-driven economy. However, to convert India's substantial IP activity into global leadership in innovation, further attention is required on enforcement, commercialisation, and access. A dynamic, inclusive, and technologically responsive IPR system remains central to realising the aspirations of Indian researchers, businesses, and communities in the years ahead.



KISAN DIVAS: HONOURING THE FARMERS OF INDIA

Article ID: AG-VO5-I12-57**Rajeshwari Desai*, Kusuma N H**, Sangeeta B D*****

* Senior Scientist, AICRP-WIA, University of Agricultural Sciences, Dharwad-5, Karnataka.

** Field Assistant, AICRP-WIA, University of Agricultural Sciences, Dharwad-5, Karnataka.

*** Field Assistant, AICRP-WIA, University of Agricultural Sciences, Dharwad-5, Karnataka.

*Corresponding Author Email ID: rajeshwarimd@uasd.in

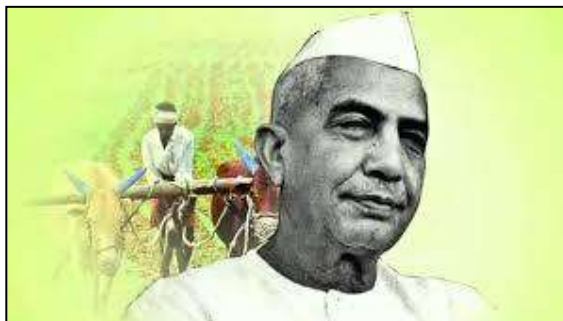
Abstract

Kisan Divas, held annually on 23rd December, is a national tribute to the farmers of India and commemorates the birth anniversary of Chaudhary Charan Singh, the fifth Prime Minister of India and a visionary agricultural reformer. This article looks into the historical significance of the day and highlighting the indispensable role of farmers in India's economy, society, and food security. It also reviews the contemporary challenges faced by farmers, the major government initiatives addressing these issues, emerging innovations in the agricultural sector, and the increasing participation of women in farming. The article concludes by highlighting the need for sustainable solutions and collective responsibility to ensure a prosperous future for Indian agriculture.



Introduction

India is a land where agriculture forms the backbone of the economy, supporting nearly half of the population. To acknowledge the efforts, sacrifices, and contributions of the farming



community, India celebrates Kisan Divas or National Farmers' Day every year on 23rd December. The day marks the birth anniversary of Chaudhary Charan Singh, a farmer-turned-leader whose life was dedicated to improving the lives of cultivators and formulating farmer-centric policies.

On this day, awareness programs, seminars, agricultural exhibitions, and discussions are organized across the country to highlight farmer welfare, agricultural development, and the need for technological advancement in farming. Kisan Divas is not merely a celebration—it is a reminder of the nation's responsibility towards those who tirelessly sow the seeds that feed millions.

Historical Background

Chaudhary Charan Singh, born on 23rd December 1902, was deeply connected to the agricultural roots of India. His important contributions include:

1. Formulating the Debt Redemption Bill (1939):

Charan Singh played a crucial role in drafting the Debt Redemption Bill of 1939, a landmark legislation that aimed to provide immediate and long-term relief to farmers who were trapped in chronic debt cycles. At a time when rural households were exploited by moneylenders charging exorbitant interest rates, this bill helped reduce accumulated debts, protected farmers from unfair mortgage conditions, and prevented the loss of agricultural land. It marked one of the earliest systemic efforts to improve the financial stability of peasant communities.

2. Land Reforms:

He was a strong advocate of comprehensive land reforms to rectify inequalities in land ownership. Charan Singh believed that equitable land distribution was essential for social justice and economic progress in rural India. He emphasized protecting the rights of small and marginal farmers, ensuring they had secure access to land, and promoting measures that prevented concentration of land in the hands of a few.

3. Abolition of the Zamindari System:

Charan Singh's contributions were vital in abolishing the exploitative Zamindari system. He supported policies that transferred land ownership rights from absentee landlords to actual cultivators, thereby giving farmers control over the land they worked on. This shift empowered rural communities, improved their economic independence, and laid the foundation for modern

agrarian reforms. Through this, he helped create a more just and farmer-centric agricultural structure.

4. Pro-farmer Leadership as Prime Minister (1979–80):

During his tenure as the Prime Minister of India, Charan Singh continued to champion the cause of farmers. He stressed the need for enhancing agricultural productivity through scientific farming practices, better irrigation facilities, and access to credit. His governance focused on rural welfare schemes, strengthening cooperative movements, boosting minimum support prices (MSP), and ensuring that national policies prioritized agrarian development. His leadership reflected his lifelong commitment to uplifting rural communities and protecting farmer interests. To honour his legacy and lifelong commitment to farmers, the Government of India declared 23rd December as National Farmers' Day.

Importance of Farmers in the Indian Economy

Farmers occupy an indispensable position in India's economic and social structure. As primary food producers, they serve as the **backbone of national food security**, ensuring a continuous supply of food grains, pulses, fruits, vegetables, and livestock products. This steady availability of nutritious food supports the health and wellbeing of millions of people across the country. Beyond feeding the nation, the **agriculture sector contributes substantially to India's GDP** and remains one of the most significant pillars of the economy. Even with growing industrialization, agriculture continues to be a major source of livelihood for a large portion of the population.

A striking indicator of this importance is that **more than 40% of India's workforce is engaged in agriculture and allied sectors** such as dairy farming, fisheries, poultry, and horticulture. These activities not only generate employment but also help reduce rural poverty and provide income stability to millions of households. Additionally, farming in India is deeply intertwined with the country's **cultural heritage and traditions**. Many festivals—such as Pongal, Baisakhi, Onam, and Makar Sankranti—celebrate the agricultural cycle, highlighting the cultural reverence for the farming community.

Furthermore, agriculture acts as a key driver of **rural development**. It stimulates growth in allied industries, including food processing, packaging, storage, transportation, and agricultural machinery. These linkages create additional employment opportunities and support the overall rural economy.

Present-Day Challenges Faced by Farmers

Despite their crucial contribution to India's economy and food security, farmers today encounter numerous challenges that directly affect their livelihood, productivity, and overall stability.

- **Fragmented Landholdings:**

Rapid population growth and the inheritance-based division of land have resulted in extremely small and fragmented agricultural plots. These tiny farms limit the use of modern machinery, reduce economies of scale, and ultimately make farming less profitable.

- **Climate Change and Unpredictable Weather:**

Farmers are increasingly vulnerable to irregular monsoons, prolonged droughts, sudden floods, heatwaves, and other climate-related events. These unpredictable weather patterns lead to crop failures, reduced yields, and higher risks for those dependent on rain-fed agriculture.

- **High Input Costs:**

The prices of essential agricultural inputs—such as fertilizers, pesticides, hybrid seeds, irrigation equipment, and machinery—are rising steadily. For small and marginal farmers, these expenses create heavy financial burdens and reduce profit margins.

- **Market Fluctuations:**

Agricultural commodity prices often fluctuate due to changes in demand, supply, and market conditions. Without guaranteed prices or proper market linkages, farmers face uncertain and unstable incomes.

- **Lack of Storage and Infrastructure:**

Inadequate cold storage, warehousing, and transportation facilities lead to significant post-harvest losses. Perishable crops, particularly fruits and vegetables, are at higher risk of spoilage before reaching markets.

- **Credit and Debt Issues:**

Limited access to institutional credit forces many farmers to rely on informal loans with high interest rates. When crops fail, they struggle to repay debts, creating long-term financial distress.

- **Limited Access to Technology:**

Many farmers lack knowledge, training, or financial resources to adopt modern technologies such as precision farming, advanced irrigation systems, or high-yield crop varieties. This limits productivity and efficiency.

These interconnected challenges highlight the urgent need for stronger, sustained support systems and comprehensive farmer welfare initiatives.

Major Government Schemes for Farmers

1. Pradhan Mantri Kisan Samman Nidhi (PM-KISAN)

- **Launch & Implementing Authority:** The scheme was announced in the 2019 Interim Union Budget by Piyush Goyal (then-Finance Minister) on 1 February 2019, and formally launched by Narendra Modi on 24 February 2019 in Gorakhpur, Uttar Pradesh.
- **Purpose & Benefit:** PM-KISAN provides ₹6,000 per year to eligible land-holding farmer families, paid in three equal installments of ₹2,000 each. The intent is to give small and marginal farmers (and subsequently all eligible landholders) direct income support to meet basic agricultural and domestic needs.
- **Coverage and Funding:** It is a Central Sector Scheme fully funded by the Government of India.

2. Pradhan Mantri Fasal Bima Yojana (PMFBY)

- **Launch & Implementing Authority:** Launched by Prime Minister Narendra Modi on 18 February 2016.
- **Purpose:** PMFBY is a crop-insurance scheme designed to protect farmers against yield losses or crop failure due to natural calamities (drought, flood, unseasonal rain, hailstorms), pests, and diseases. It aims to stabilize farmer income and reduce risk.
- **Coverage:** The scheme provides comprehensive coverage for the entire cropping cycle — from pre-sowing to post-harvest.
- **Premium & Subsidy Structure:** Premium burden on the farmer is made small (e.g., 2% of sum insured for Kharif cereals/pulses, 1.5% for Rabi, and up to 5% for commercial/horticultural crops). The remaining premium subsidy is shared between the Central and State governments.

3. Kisan Credit Card (KCC) Scheme

- **Launch & Implementing Bodies:** Introduced in August 1998, conceptualized by NABARD (National Bank for Agriculture and Rural Development) based on recommendations of the R. V. Gupta Committee.
- **Purpose:** The KCC scheme provides timely and adequate credit to farmers for agricultural operations — including purchase of seeds, fertilizers, pesticides, and other inputs — as well as for investment needs. It supports both crop cultivation and allied activities.
- **Structure:** It offers both short-term cash credit (for crop inputs/working capital) and **term loans** (for farm infrastructure, machinery, allied activities, etc.).
- **Coverage:** The scheme is widespread — KCCs are issued by public sector banks, regional rural banks, cooperative banks and other financial institutions throughout India.

4. Soil Health Card Scheme

- **Launch:** The scheme began in 2015.
- **Implementing Authority:** It is run by the Ministry of Agriculture & Farmers Welfare.
- **Purpose:** The Soil Health Card Scheme aims to promote balanced fertiliser use and sustainable soil management. Under the scheme, farmers receive a “soil health card” which gives information about the nutrient status of their soil — helping them to choose appropriate fertilizers and improve crop yields.

5. e-NAM (National Agriculture Market) ★★☆☆

- **Launch / Purpose:** e-NAM was launched in April 14, 2016 to create a unified national digital market for agricultural produce. Its goals are to integrate local mandis (agricultural markets) across India, improve price transparency, and facilitate farmers getting fair prices for their produce.
- **Impact:** By linking markets digitally, e-NAM helps reduce intermediaries, offers better market access to farmers, and aims to standardize trading practices across states.

6. Agri-Infrastructure Fund (under Atmanirbhar Bharat)

- **Launch / Purpose :** The scheme was approved by the Union Cabinet in July 2020. Under the broader umbrella of Atmanirbhar Bharat Abhiyan, the government launched the Agri-Infrastructure Fund to boost storage, processing and supply-chain infrastructure in agriculture. This helps reduce post-harvest losses, improve value addition, and support long-term agricultural growth.

- **Purpose:** The fund supports building warehouses, cold storage units, food-processing units, supply-chain infrastructure, and other facilities — thus improving the overall agribusiness ecosystem.

Innovations and Modern Agricultural Practices

India's agricultural sector is undergoing a major transformation as new technologies, scientific tools, and innovative practices reshape the future of farming. These advancements aim to increase productivity, reduce costs, and make agriculture more sustainable and profitable for farmers.

a) Precision Farming: Precision farming involves the use of advanced tools such as GPS-based devices, satellite imagery, soil sensors, and data analytics to monitor crop conditions accurately. By assessing soil moisture, nutrient levels, and plant health, farmers can apply water, fertilizers, and pesticides only where needed. This not only boosts yields but also reduces wastage and environmental impact, making farming more efficient and cost-effective.

b) Drone Technology: Drones are becoming widely used for agricultural operations. They help in spraying pesticides and fertilizers uniformly across fields, monitoring crop growth, detecting diseases early, and creating detailed aerial maps. Drone usage saves time, reduces labor dependency, and ensures safer application of chemicals.

c) Organic and Sustainable Farming: Increasing awareness about health and environmental protection has led to a shift toward organic farming. This method avoids synthetic chemicals and relies on natural fertilizers, crop rotation, and eco-friendly pest control. Sustainable farming practices help maintain soil fertility, protect biodiversity, and produce healthier food.

d) Hydroponics and Vertical Farming: These innovative techniques allow cultivation without soil using nutrient-rich water solutions. Hydroponics, along with vertical farming concepts, is ideal for urban areas with limited land. They require less water, offer faster growth, and allow year-round cultivation of vegetables and herbs.

e) Agri-Startups: A growing number of agri-startups are revolutionizing the sector by providing mobile-based advisory services, digital marketplaces, weather forecasting tools, precision equipment, and doorstep delivery of seeds and fertilizers. These startups bridge gaps between farmers and markets, improving productivity and income.

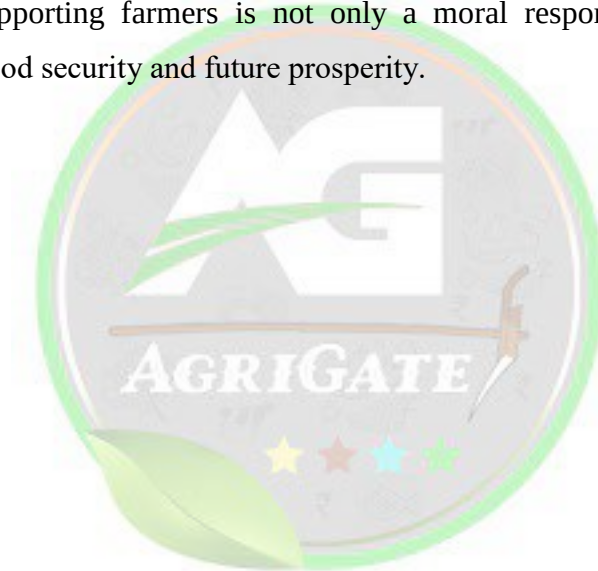
f) Farmer Producer Organizations (FPOs): FPOs bring small and marginal farmers together as collective groups. By uniting, farmers gain better bargaining power, easier access to quality

inputs, modern technologies, credit facilities, and larger markets. FPOs help reduce production costs and improve market prices, strengthening the rural economy.

Conclusion

Kisan Divas is not just a day of celebration—it is a reminder of the nation's duty to its farmers, who work tirelessly under the sun and rain to feed millions. As the backbone of India's economy and culture, farmers deserve respect, resources, and recognition. Strengthening their livelihood, improving agricultural infrastructure, and ensuring fair market access are crucial for India's overall development.

Honouring farmers on Kisan Divas is meaningful only when accompanied by long-term commitment, sustainable reforms, and collective action to build a prosperous and resilient agricultural sector. Supporting farmers is not only a moral responsibility—it is the key to ensuring the nation's food security and future prosperity.



JELLYFISH MUCUS AS A NOVEL ADSORBENT FOR MICRO- AND NANO-PLASTICS REMOVAL FROM SEAWATER

Article ID: AG-VO5-I12-58

A. Nazeela Barvin^{1*}, D. Manimekalai², A. Aparna¹, S. Bhaskar¹

¹PG Scholar, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu

²Assistant Professor, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute,

Thoothukudi, Tamil Nadu, India

*Corresponding Author Email ID: nazeelabarvin@gmail.com

Abstract

Micro- and nano-plastics have emerged as pervasive contaminants in marine environments, posing a threat to aquatic organisms and entering global food chains. Conventional filtration systems struggle to capture these ultrafine particles due to their size and chemical stability. Recent scientific discoveries reveal that jellyfish mucus, rich in natural mucins and glycoproteins, can effectively bind and remove micro- and nano-plastics through adsorption–bridging and mesh filtration mechanisms. Studies demonstrate removal efficiencies of 60–90%, surpassing many chemical coagulants used in wastewater treatment. As a biodegradable, renewable, and non-toxic biomaterial, jellyfish mucus presents a promising nature-based solution for sustainable marine pollution mitigation. This article highlights the scientific principles, ecological relevance, and future applications of jellyfish mucus as an innovative adsorbent for seawater purification.

Keywords: Jellyfish mucus; microplastics; nanoplastics; mucins; natural adsorbent; bio-flocculation; marine pollution.

Introduction

The global rise in plastic production has resulted in an explosion of micro- and nano-plastic pollution in the world's oceans. These tiny particles, originating from synthetic textiles,

packaging materials, personal care products, and degraded plastic litter, are now found in every marine compartment from surface waters to deep-sea sediments. Their small size allows them to be ingested by plankton, fish, shellfish, and even humans. Traditional removal methods such as coagulation, membrane filtration, and chemical adsorption often fail to capture particles smaller than 1 μm . This has prompted researchers to explore biological alternatives solutions that are gentle on marine life yet powerful enough to trap plastic contaminants. One such unexpected discovery is the ability of jellyfish mucus to act as a natural microplastic filter.

Jellyfish Mucus: Composition and Biological Function

Jellyfish mucus is a complex and multifunctional secretion, composed of:

- **Mucins** – large, glycosylated proteins that provide a sticky, gel-like matrix.
- **Polysaccharides** – sugar-based molecules that enhance the structural integrity of the mucus.
- **Water-binding molecules** – help maintain hydration and flexibility of the mucus.
- **Charged functional groups** – contribute to the mucus's ability to interact with various particles, including micro- and nano-plastics.

In their natural environment, jellyfish secrete mucus for several purposes:

- **Protection of delicate tissues** from physical damage and pathogens.
- **Trapping food particles**, facilitating feeding.
- **Deterring predators** through physical entanglement or chemical cues.
- **Responding to physical stress**, such as turbulence or environmental changes.

The same structural stickiness and chemical versatility, originally evolved to support jellyfish survival, also makes the mucus highly effective at binding micro- and nano-plastics in aquatic environments. By exploiting these natural properties, researchers can harness jellyfish mucus as a sustainable and biodegradable adsorbent for water purification and pollution control.

Mechanism of Micro- and Nano-Plastic Removal by Jellyfish Mucus

The removal of micro- and nano-plastics from aquatic environments using jellyfish mucus relies on a combination of chemical and physical interactions. This process can be understood through four main mechanisms:

1. Electrostatic Attraction

Micro- and nano-plastic particles often carry surface charges, either positive or negative, depending on their polymer type and environmental conditions. Jellyfish mucin

molecules contain both positively and negatively charged functional groups, enabling strong electrostatic interactions. These attractions pull plastic particles toward the mucus, initiating the first step in their removal.

2. Adsorption–Bridging

Mucin molecules have long, flexible chains that can act as “biological bridges.” These chains connect multiple plastic particles, effectively linking them together. This adsorption–bridging process facilitates the formation of larger particle clusters, or flocs, which are much easier to separate from the water compared to individual nanoparticles.

3. Mesh Filtration

The mucus secreted by jellyfish forms a soft, gel-like network, resembling a loose hydrogel. Nanoplastics become physically trapped within this three-dimensional mesh, preventing their free movement. This structural entrapment adds a mechanical layer of filtration in addition to the chemical interactions.

4. Rapid Floc Formation

Once captured through electrostatic attraction and mesh entrapment, the plastic particles aggregate rapidly into visible flocs. These clumps can then be removed by simple sedimentation, filtration, or skimming techniques, making the overall cleanup process fast, efficient, and scalable for practical applications.

Efficiency Compared to Traditional Methods

Recent studies have shown remarkable results:

- **60–90% removal** of nano-sized polystyrene and PMMA particles
- Outperforms ferric chloride, alum, and PAC, which often show **0–40% removal**
- Works even in **complex wastewater matrices**
- Produces **non-toxic, biodegradable residues**

This makes jellyfish mucus one of the most effective natural adsorbents discovered so far.

Ecological and Sustainable Advantages

- **Biodegradable:** breaks down naturally without secondary pollution
- **Renewable:** jellyfish populations are increasing globally
- **Non-toxic:** safe for marine organisms
- **Low-energy requirement:** no chemicals or high-pressure systems needed
- **Cost-effective:** minimal processing required

The rising occurrence of jellyfish blooms provides a considerable opportunity to utilize their biomass sustainably.

Potential Applications of Jellyfish Mucus-Based Adsorbents

- **Wastewater Treatment Plants** - Jellyfish mucus offers a natural, eco-friendly alternative to traditional metal-based coagulants, helping to remove micro- and nano-plastics from wastewater streams.
- **Coastal Cleanup Systems** - Floating bioremediation units utilizing mucus-based adsorbents can trap plastics before they reach sensitive coastal and marine ecosystems, reducing environmental pollution at the source.
- **Desalination Pre-Filtration** - In desalination facilities, mucus-based filters can lower the microplastic load prior to reverse osmosis, protecting membranes and improving water quality.
- **Marine Research Stations** - Portable filtration kits using jellyfish mucus can facilitate field sampling and monitoring of microplastics, providing researchers with a low-cost and efficient tool for marine studies.
- **Jellyfish-Mucin Hydrogel Development** - Engineered hydrogels derived from jellyfish mucin can be designed as reusable filtration systems capable of capturing large volumes of plastics, offering scalable solutions for both freshwater and marine environments.

Future Prospects and Challenges

While jellyfish mucus offers impressive potential, future research must address:

- large-scale harvesting without ecological disruption
- stabilization of mucus for long-term use
- integration into existing purification technologies
- cost optimization for industrial applications

Advancements in biotechnology may allow scientists to replicate or synthesize jellyfish mucins without depending on wild populations.

Conclusion

Jellyfish, often overlooked as simple gelatinous organisms, possess extraordinary biological materials with powerful environmental applications. Their mucus, rich in functional mucins, has emerged as a promising natural adsorbent capable of removing even the smallest

plastic particles from seawater. As microplastic pollution continues to rise, nature-inspired solutions like jellyfish mucus offer hope for a cleaner, more resilient future.

This nature-based approach aligns with the increasing global need for sustainable, gentle, and effective methods to protect marine environments. Much like jellyfish themselves masters of efficiency and adaptation. This innovative discovery may reshape how we address one of the most challenging pollutants of our time.

References

- Ben-David, E. A., Habibi, M., Haddad, E., Sammar, M., Angel, D. L., Dror, H., ... & Sabbah, I. (2023). Mechanism of nanoplastics capture by jellyfish mucin and its potential as a sustainable water treatment technology. *Science of the Total Environment*, 869, 161824.
- Lengar, Ž., Klun, K., Dogsa, I., Rotter, A., & Stopar, D. (2021). Sequestration of polystyrene microplastics by jellyfish mucus. *Frontiers in marine science*, 8, 690749.
- Geum, S. W., & Yeo, M. K. (2022). Reduction in toxicity of polystyrene nanoplastics combined with phenanthrene through binding of jellyfish mucin with nanoplastics. *Nanomaterials*, 12(9), 1427.

OHMIC HEATING IN FOOD APPLICATIONS

Article ID: AG-VO5-I12-59**Amuthaselvi.G***

Department of Food Process Engineering, Agricultural Engineering College &
Research Institute, Tamil Nadu Agricultural University, Coimbatore-3,
Tamil Nadu, India

*Corresponding Author Email ID: g.amuthaselvi@gmail.com

Introduction

Thermal processing is one of the most widely used methods for ensuring the safety and shelf-life of food products. Traditional thermal techniques—such as conduction, convection, and radiation—often result in non-uniform heating, long processing times, and quality degradation of heat-sensitive foods. To address these limitations, alternative thermal technologies have emerged, among which ohmic heating has proven to be one of the most promising. Ohmic heating, also referred to as Joule heating or electrical resistance heating, involves passing an alternating electric current directly through food materials, which act as resistive loads. This induces rapid and volumetric heat generation inside the product, enabling uniform temperature distribution and reduced thermal damage.

The growing interest in ohmic heating is driven by consumer demand for minimally processed foods with high nutritional and sensory quality. In addition, this technology aligns with global priorities for sustainability, energy efficiency, and waste reduction. Ohmic heating is currently applied or studied in multiple sectors, including beverage processing, dairy industry, fruit and vegetable preservation, meat and seafood processing, ready-to-eat meals, and extraction systems. It is particularly valuable for processing particulate-containing foods—such as soups, fruit pieces, and sauces—where achieving uniform heat penetration is challenging using traditional methods.

Principles and Mechanisms of Ohmic Heating

Electrical Resistance and Heat Generation

Ohmic heating operates on Joule's Law, which states that when electric current (I) passes through a conductive material with resistance (R), heat (H) is generated proportionally:

$$H = I^2 R t$$

Food materials conduct electricity through ions present in water, minerals, salts, organic acids, and other components. When an alternating current passes through the food, these ions oscillate, causing frictional heating. Because heat is generated internally rather than transferred from external surfaces, temperature profiles are more uniform, reducing thermal gradients and over-processing.

Role of Electrical Conductivity

Electrical conductivity (EC) is a critical factor determining heating rate and efficiency. EC depends on:

- Ionic concentration
- Temperature
- pH
- Moisture content
- Composition (e.g., fat, sugar, protein)
- Particle size and distribution

Foods with higher EC heat faster. EC typically increases with temperature, creating a positive feedback loop known as conductivity–temperature dependence.

Frequency and Voltage Gradients

Most ohmic systems operate at **50–60 Hz**, similar to household power supply. However, higher frequencies (1–100 kHz) reduce electrochemical reactions at electrodes, minimizing corrosion. Optimal voltage gradients typically range from **10–20 V/cm**, though they may vary depending on product characteristics.

Electrodes and Corrosion Issues

Electrode material selection is crucial because foods often contain electrolytes that intensify corrosion. Common materials include:

- Stainless steel
- Titanium

- Platinum
- Carbon-based electrodes

Surface coatings and high-frequency AC are used to avoid electrochemical fouling, pitting, and metal leaching.

Heat and Mass Transfer in Ohmic Systems

Ohmic heating produces volumetric heat generation, minimizing cold spots and reducing the need for agitation. However, foods with non-uniform EC may still exhibit localized overheating or insufficient heating. Mass transfer (e.g., moisture migration, steam formation) is enhanced due to rapid internal heat buildup, improving processes such as drying and extraction.

Advantages of Ohmic Heating

Rapid and Uniform Heating

Ohmic heating eliminates external temperature gradients and enables immediate heat generation throughout the product. This results in rapid heating rates (up to 5–10°C/s), significantly faster than conventional systems.

Improved Nutritional and Sensory Quality

Shorter thermal exposure reduces:

- Vitamin degradation
- Pigment loss
- Texture softening
- Flavor alterations

Ohmic heating is particularly effective for delicate products such as fruit purees, juices, and vegetables.

Energy Efficiency

Ohmic heating has an energy efficiency of **90–95%**, far superior to steam-based or conduction-based systems. Minimal heat is lost to the environment.

Compatibility with Particulates

Unlike conventional heating, where particulates heat more slowly than liquids, ohmic heating heats solid and liquid phases at comparable rates.

Applications of Ohmic Heating in Food Processing

Pasteurization and Sterilization

Ohmic heating is widely used for microbial inactivation in:

- Fruit juices
- Tomato products
- Dairy beverages
- Broths and soups
- Pulsed sauces

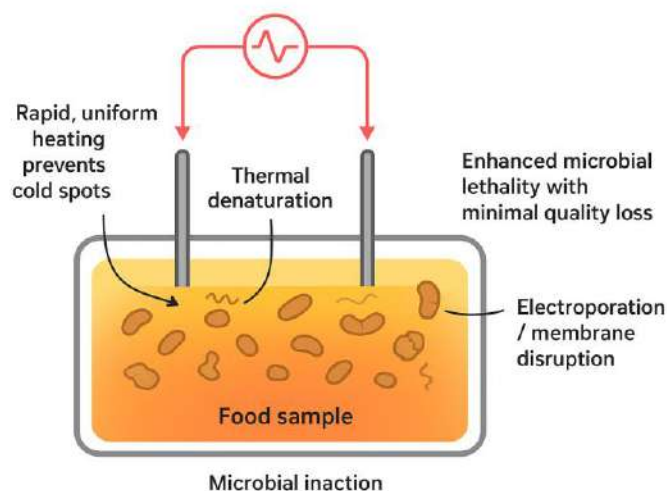
The combined effects of heat and electric field improve lethality, allowing lower processing temperatures.

Microbial Inactivation Mechanisms

Microbial inactivation arises from:

1. **Thermal effects:** Rapid heating damages proteins, DNA, and membranes.
2. **Electrical effects:** Electric fields cause **electroporation**, leading to leakage of intracellular content.
3. **Synergistic effects:** Combined stresses enhance inactivation rates compared to thermal heating alone.

Microbial inactivation is a critical aspect of ohmic heating, as it ensures the safety and shelf life of processed foods while preserving quality. Unlike conventional heating, where heat is transferred from an external source and may produce uneven temperature distribution, ohmic heating generates heat volumetrically within the food matrix, allowing rapid and uniform temperature rise.



This internal heating, combined with the effects of the applied electric field, contributes to enhanced microbial lethality. The primary mechanism of inactivation is thermal denaturation,

where the rapid rise in temperature disrupts the structural integrity of microbial proteins, enzymes, and nucleic acids, ultimately leading to cell death. However, ohmic heating also exhibits non-thermal effects associated with the passage of an alternating electric current. These effects include electroporation, where the cell membrane becomes permeabilized due to electrical stress, causing leakage of intracellular components, loss of membrane potential, and eventual cell lysis. This combination of thermal and electrical stresses accelerates microbial inactivation compared to conventional heating at the same temperature.

Ohmic heating is particularly effective against both vegetative cells and heat-sensitive spores. The uniform volumetric heating prevents cold spots, which are common in traditional methods and often allow microbial survival in the product's interior. Additionally, the inactivation efficiency can be influenced by factors such as electrical conductivity of the food, moisture content, solute composition, pH, and the frequency and intensity of the applied current. Foods with higher ionic content conduct electricity more effectively, facilitating faster heat generation and improved microbial reduction.

Studies have demonstrated that ohmic heating can achieve significant reductions in common foodborne pathogens, including *Escherichia coli*, *Salmonella spp.*, *Listeria monocytogenes*, and *Bacillus cereus*, as well as spoilage microorganisms responsible for enzymatic degradation and off-flavors. Furthermore, the synergistic effect of combined thermal and electrical stresses reduces the time and temperature required for pasteurization or sterilization, thereby preserving heat-sensitive nutrients, flavors, and textures in processed foods. Overall, ohmic heating provides a highly effective, rapid, and energy-efficient means of microbial inactivation, offering both safety and quality advantages over conventional thermal treatments

Blanching in Ohmic Heating

Blanching is an essential pretreatment used in the food industry to inactivate enzymes, reduce microbial load, soften tissues, and preserve the color and nutritional quality of fruits and vegetables prior to further processing such as freezing, drying, or canning. Traditional blanching methods—hot water blanching and steam blanching—often suffer from drawbacks including prolonged heating times, non-uniform heat transfer, excessive leaching of water-soluble nutrients, and higher energy consumption. Ohmic heating has emerged as an advanced alternative that addresses many of these limitations by delivering rapid and uniform volumetric

heating directly within the food matrix. In ohmic blanching, an alternating electric current is passed through the food material, causing internal heat generation due to electrical resistance. This mechanism ensures that heat is produced evenly throughout the product, allowing rapid temperature rise and precise control of thermal exposure.

The efficiency of ohmic blanching lies in its ability to inactivate enzymes such as polyphenol oxidase (PPO), peroxidase (POD), and pectin methylesterase (PME) within much shorter processing times compared to conventional methods. Because heating is internal and uniform, there is minimal risk of overprocessing the surface layers while the core remains insufficiently heated—a common issue in conventional blanching. This rapid enzyme inactivation is particularly beneficial for heat-sensitive fruits and vegetables, allowing greater retention of vitamins (e.g., vitamin C, folate) and phytochemicals (e.g., anthocyanins, carotenoids). Furthermore, since ohmic blanching does not require immersion in large volumes of water, leaching losses of minerals, sugars, organic acids, and pigments are significantly minimized. The absence of direct water contact also improves sustainability by reducing wastewater volume and lowering energy demands.

From a physical quality standpoint, ohmic blanching enhances texture preservation due to reduced processing time and controlled thermal exposure. The technique softens tissues adequately for downstream processes such as peeling or cutting without causing the excessive mushiness often associated with prolonged hot-water blanching. In vegetables like carrots, potatoes, beans, and peas, ohmic blanching has been shown to maintain structural firmness while improving color retention by preventing enzymatic browning and pigment degradation. Additionally, the process exhibits excellent microbial reduction, improving the safety and shelf life of minimally processed produce.

Another significant advantage of ohmic blanching is its compatibility with continuous processing. Ohmic systems can be integrated into industrial lines where food pieces are conveyed through electrodes, enabling high-throughput operations with precise temperature control. This adaptability makes the technology suitable for a wide range of fruit and vegetable products, including leafy vegetables, root crops, and delicate items like berries. Moreover, the electrical conductivity of foods plays a crucial role in blanching efficiency; products with higher moisture and electrolyte content heat faster, while conductivity can be enhanced when necessary

through the addition of safe salts. As a result, ohmic blanching is both versatile and tunable, allowing processors to optimize heating profiles based on product type.

Overall, ohmic heating represents a superior blanching technology that offers improved nutrient retention, higher energy efficiency, better color and texture quality, and reduced environmental impact compared to conventional blanching methods. Its ability to deliver rapid, uniform, and controllable heating while minimizing processing losses makes it particularly attractive for high-value food products aimed at maintaining fresh-like quality. As the food industry increasingly adopts sustainable and high-efficiency thermal processing technologies, ohmic blanching continues to gain attention as a promising solution for enhancing product quality and process performance.

Cooking and Ready-to-Eat (RTE) Meals Using Ohmic Heating

Ohmic heating has emerged as a transformative technology in the preparation of cooked and ready-to-eat (RTE) meals, offering faster, more uniform, and energy-efficient heating compared to traditional thermal processes such as retorting, steaming, or conduction-based cooking. In ohmic cooking, heat is generated directly within the food matrix by passing an alternating electric current through the product, enabling rapid and homogeneous temperature elevation across both liquid and solid phases. This is especially beneficial for multi-component meals—such as curries, soups, gravies, pasta dishes, and mixed vegetable or meat preparations—where conventional heating often leads to temperature gradients, overprocessing of the external layers, and underprocessing of the internal components. Ohmic heating eliminates these inconsistencies by ensuring volumetric heating, thereby reducing cooking times and preserving the sensory attributes of all components in a complex food system.

In RTE meal production, maintaining product quality is of utmost importance, particularly in terms of texture, color, nutritional value, and flavor stability. Ohmic heating supports these quality parameters by minimizing prolonged exposure to high temperatures, which is common in retort-based processing. For example, vegetables in RTE dishes retain better firmness and color, while meats maintain juiciness and structural integrity due to reduced thermal degradation of proteins and connective tissues. Furthermore, since ohmic heating does not involve direct contact with high-temperature surfaces, issues such as scorching, burning, or nutrient loss due to surface overheating are significantly minimized. The gentle but fast heating

profile ensures superior retention of heat-sensitive vitamins, antioxidants, and phytonutrients, making ohmic-cooked meals closer in quality to freshly prepared dishes.

One of the major advantages of ohmic heating for RTE meals is its ability to achieve rapid and uniform microbial inactivation, ensuring safety and extended shelf life. During cooking, pathogenic and spoilage microorganisms are rapidly destroyed as the entire volume of the food reaches lethal temperatures simultaneously, unlike conventional heating where cold spots are harder to eliminate. This uniformity is critically important for viscous or particulate foods such as dhal, sauces, gravies, stews, and meat-based curries. Ohmic heating has demonstrated effectiveness against common foodborne pathogens including *E. coli*, *Salmonella*, *Listeria monocytogenes*, and heat-resistant spore-formers when combined with suitable time–temperature combinations. The precise control offered by ohmic systems also reduces variability in microbial reduction outcomes, making the method reliable for industrial-scale RTE meal manufacturing.

From a processing perspective, ohmic heating is highly compatible with continuous and automated systems, enabling large-scale production of high-quality cooked meals with consistent quality. Industrial ohmic cookers and continuous flow ohmic systems can handle particulates suspended in liquids—such as meat cubes in gravy or vegetable chunks in curry—without causing structural damage or breakup of delicate components. This is because the heating mechanism does not rely on fluid convection or mechanical agitation. In addition, the ability of ohmic systems to instantaneously switch heating intensity allows processors to optimize heating rates for different ingredients within the same product, offering unprecedented flexibility in designing RTE formulations. The technology also reduces overall energy consumption and processing time, contributing to lower production costs and improved sustainability.

Another important benefit of ohmic heating in the RTE sector is the enhancement of flavor profiles. Rapid internal heating minimizes thermal degradation of volatile compounds, allowing meals to retain their natural aroma and fresh-cooked flavor. Traditional methods such as sterilization often lead to “overcooked” or “flat” flavors due to extended exposure to high temperatures, particularly in gravies and sauces. Ohmic heating mitigates this issue, producing meals with improved sensory appeal and consumer acceptability. For this reason, several commercial RTE products—especially premium or “fresh-like” categories—are increasingly exploring ohmic heating as a core processing technology.

Thawing and Tempering

Thawing and tempering are critical steps in the processing of frozen foods, as they directly influence product quality, safety, and downstream processing efficiency. Conventional thawing methods—air thawing, water immersion, or conduction-based heating—often result in uneven temperature distribution, long processing times, and quality deterioration, including drip loss, textural degradation, microbial growth, and nutrient leaching. Ohmic heating presents a highly effective alternative for these operations by utilizing internal volumetric heating, where an alternating electric current passes through the frozen food matrix, generating heat uniformly due to electrical resistance. This method significantly reduces thawing times while ensuring uniform temperature distribution, thereby preventing the formation of cold spots and over-heating of surface layers that commonly occur with conventional thawing techniques.

In thawing applications, ohmic heating maintains the structural integrity and texture of delicate foods such as meat, seafood, fruits, and vegetables. Rapid and uniform heating minimizes water loss and reduces the formation of exudates, preserving juiciness and sensory quality. For example, fish fillets and meat blocks retain higher water-holding capacity and firmer texture when thawed using ohmic methods compared to air or water immersion. Similarly, thawing of frozen fruits using ohmic heating reduces cell damage and maintains color, flavor, and nutritional quality. The ability of ohmic systems to control heating rates precisely allows processors to achieve desired tempering temperatures without partially cooking the product, which is particularly important in products intended for further thermal processing or immediate consumption.

Ohmic tempering also enhances food safety by maintaining the product within safe temperature ranges, reducing microbial proliferation during the critical pre-processing stage. Additionally, ohmic heating enables uniform tempering of high-moisture and multi-component frozen products, such as ready-to-cook meals, soups, and vegetable mixtures, where different constituents may have varying thermal conductivities. Industrial applications benefit from continuous ohmic thawing systems, which can handle large volumes of frozen products efficiently, improving production throughput while minimizing energy consumption compared to conventional thawing methods. Overall, ohmic heating offers a technologically advanced, energy-efficient, and quality-preserving approach to thawing and tempering frozen foods,

making it a valuable tool for modern food processing operations focused on maintaining nutritional, sensory, and microbiological integrity.

Concentration and Evaporation

Ohmic heating is used for gentle concentration of: Fruit juices, Milk and dairy concentrates and Herbal extracts. Advantages include shorter residence times and minimized caramelization. Ohmic heating has been effectively employed in the concentration and evaporation of liquid foods, offering significant advantages over conventional thermal techniques such as open-pan evaporation or vacuum evaporation. In traditional methods, heat is transferred externally, which often results in prolonged heating times, uneven temperature distribution, thermal degradation of heat-sensitive nutrients, caramelization, and loss of flavor compounds. In contrast, ohmic heating generates heat volumetrically within the food medium by passing an alternating electric current through the conductive liquid. This internal heat generation allows rapid and uniform temperature rise throughout the liquid, minimizing thermal gradients, reducing energy consumption, and preserving product quality during concentration or evaporation. The method is particularly advantageous for viscous liquids, fruit juices, milk, dairy concentrates, sauces, and herbal extracts, where uniform heating is difficult to achieve with conventional methods.

In application, ohmic heating facilitates faster evaporation rates due to enhanced internal heating and localized vapor generation. This rapid volumetric heating promotes efficient mass transfer, allowing water or volatile solvents to evaporate quickly without causing overheating at the product surface. As a result, the concentration process is not only accelerated but also preserves heat-sensitive components such as vitamins, polyphenols, pigments, and aromatic compounds, which are often degraded during prolonged conventional heating. For instance, fruit juices concentrated using ohmic heating retain higher levels of vitamin C, carotenoids, and natural flavors, while dairy concentrates maintain functional proteins and minimize Maillard browning. Moreover, ohmic-assisted concentration reduces fouling and scaling on heating surfaces, a common issue in conventional evaporators, thereby improving equipment longevity and hygiene.

Ohmic evaporation also allows precise control of the process through modulation of voltage, current, and frequency, making it suitable for sensitive products or multi-component liquids where different constituents may respond differently to heat. Hybrid systems combining

ohmic heating with vacuum evaporation further enhance energy efficiency and product quality by lowering boiling points and reducing thermal stress. Additionally, ohmic systems are scalable for industrial operations and can be integrated into continuous processing lines, supporting high-throughput and consistent product quality. Overall, ohmic heating provides a rapid, uniform, and energy-efficient approach to concentration and evaporation, making it a valuable technology for producing high-quality, nutrient-rich, and flavor-preserved liquid foods in modern food processing industries.

Effect of Ohmic Heating on Food Quality

Nutritional Quality

Ohmic heating better preserves:

- Vitamins (A, C, B-complex)
- Polyphenols
- Anthocyanins
- Heat-sensitive proteins

Sensory Quality

Consumers prefer ohmic-treated products due to improvements in:

- Color brightness
- Natural flavor retention
- Firmer texture
- Reduced browning

Physicochemical Properties

Ohmic heating reduces:

- Non-enzymatic browning
- Maillard reactions
- Fat oxidation
- Protein denaturation

While improving:

- Viscosity
- Gelation behavior
- Emulsion stability



Engineering and Design Considerations

System Configuration

Two major configurations are used:

- **Continuous flow ohmic heaters**
- **Batch ohmic systems**

Continuous systems are preferred industrially for high throughput.

Electrode Design

Key factors:

- Material (stainless steel, titanium)
- Surface area
- Spacing
- Cooling systems
- Polarity reversal

Electrode fouling reduces process efficiency and must be carefully controlled.

Power Supply and Control

A stable AC supply with:

- Adjustable voltage
- High frequency (to reduce corrosion)
- Sensors for temperature, EC, and flow rate

Real-time automatic control strategies prevent overheating.

Limitations and Challenges

Despite its advantages, several challenges persist.

Electrode Fouling and Corrosion

Electrochemical reactions lead to:

- Metal dissolution
- Pitting
- Surface deposits
- Contamination risks

High-frequency AC and inert electrode materials help mitigate this.

Electrical Conductivity Variations

Foods are heterogeneous.

Particulates may have different EC than liquid media, causing non-uniform heating.

Safety and Regulatory Concerns

Regulatory guidelines are still emerging. There is a need for:

- Standardized validation protocols
- Electrode material regulations
- Industrial safety codes

Conclusion

Ohmic heating is a transformative thermal processing technology offering rapid, uniform heating suitable for a wide range of food products. Its ability to preserve quality, improve microbial inactivation, handle particulates effectively, and reduce energy consumption positions it as a leading candidate for next-generation food processing. Although challenges remain—particularly in electrode durability, cost, and regulatory frameworks—ongoing innovations in materials, control systems, hybridization, and modeling are accelerating industrial adoption. Future developments are expected to expand commercial applications and support sustainable, high-quality food manufacturing.

References

- Agarwal, A., Kumar, R., & Pal, A. (2022). Ohmic heating technology for food processing: Principles and applications. *Food Engineering Reviews*, 14(3), 431–458. <https://doi.org/10.1007/s12393-021-09289-z>
- Assiry, A. M. (2020). Electrical conductivity and physicochemical properties of food materials during ohmic heating: A review. *Journal of Food Engineering*, 273, 109801. <https://doi.org/10.1016/j.jfoodeng.2019.109801>
- Chakraborty, S., Rao, P. S., & Mishra, H. N. (2019). Ohmic heating in food processing: A review. *Critical Reviews in Food Science and Nutrition*, 59(17), 2887–2905. <https://doi.org/10.1080/10408398.2018.1480007>
- Darvishi, H., & Najafi, G. (2021). Applications of ohmic heating in food processing and preservation. *Innovative Food Science & Emerging Technologies*, 67, 102563. <https://doi.org/10.1016/j.ifset.2020.102563>
- Kim, H. J., & Sastry, S. K. (2022). Advances in ohmic heating for food sterilization: Mechanisms and industrial applications. *Food Control*, 139, 109073. <https://doi.org/10.1016/j.foodcont.2022.109073>

- Lebovka, N., Praporscic, I., & Vorobiev, E. (2020). Ohmic heating and electroporation as innovative technologies for food processing. *Food Biophysics*, 15(1), 20–35. <https://doi.org/10.1007/s11483-019-09594-w>
- Lima, M., & Sastry, S. K. (2021). Modeling and optimization of ohmic heating of multiphase foods. *Journal of Food Process Engineering*, 44(1), e13585. <https://doi.org/10.1111/jfpe.13585>
- Marra, F., & Lyng, J. (2021). Ohmic heating: Industrial perspectives and future developments. *Current Opinion in Food Science*, 42, 191–197. <https://doi.org/10.1016/j.cofs.2021.06.006>
- Sastry, S. K., & Singh, R. P. (2020). Ohmic heating in food processing. In *Handbook of Food Engineering* (pp. 1059–1100). CRC Press.
- Zell, M., Lang, C., & Kulozik, U. (2023). The impact of ohmic heating on enzyme inactivation and quality of plant-based foods. *Food Research International*, 163, 112236. <https://doi.org/10.1016/j.foodres.2022.112236>

CORAL REEF CONNECTIVITY: HOW OCEAN CURRENTS LINK REEFS ACROSS ENTIRE REGIONS

Article ID: AG-VO5-I12-60

Aparna A^{1*}, V. Rani², D. Manimekalai³, A. Nazeela Barvin¹, S. Bhaskar¹

¹Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu

²Dean i/c, Dr. M. G. R. Fisheries College and Research Institute, Thalainayeru, Tamil Nadu.

³Assistant Professor, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu. India

*Corresponding Author Email ID: aparna13122002@gmail.com

Abstract

Coral reefs are interconnected biological systems rather than isolated habitats. Their long-term survival depends on connectivity, a process through which larvae, genes, nutrients, and ecological functions are exchanged between distant reef systems via ocean currents. This dynamic linkage supports biodiversity, stabilises populations, and enhances ecosystem resilience. Ocean currents transport coral larvae across hundreds of kilometres, forming networks of “source” and “sink” reefs that collectively sustain coral populations across entire marine regions. Connectivity governs recruitment, genetic diversity, and recovery from disturbances such as bleaching and cyclones. With climate change altering current patterns and larval survival, understanding and protecting connectivity pathways has become critical for conservation planning.

Keywords: Coral Connectivity, Larval Dispersal, Ocean Currents, Source-Sink Dynamics, Reef Resilience, Marine Protected Areas

Introduction

Coral reefs are among the most biologically diverse ecosystems on Earth, yet their persistence depends on far more than local ecological conditions. Increasing evidence suggests

that reefs are not isolated ecological features; instead, they form highly interconnected networks linked across large spatial scales by the movement of water masses, larvae, nutrients, and even chemical signals. This phenomenon, known as coral reef connectivity, has become a major focus in marine ecology because it reshapes how scientists interpret reef resilience, conservation prioritization and long-term stability under climate change.

Connectivity research has evolved significantly over the past two decades due to advances in ocean circulation modelling, genomics, remote sensing and larval ecology. Modern perspectives now view reefs as metapopulations—networks of interacting populations linked by dispersal. This metapopulation view challenges the traditional “local reef” conservation approach that addressed individual reefs in isolation.

Conceptual Foundations of Reef Connectivity

Connectivity in coral reef science is broadly classified into demographic, genetic, ecological, and physical connectivity. Each type informs different aspects of reef functioning.

Demographic Connectivity

Demographic connectivity refers to the flow of individuals (mostly larvae) between populations, influencing recruitment rates and population dynamics. A reef receiving larvae from multiple other reefs maintains stable populations even after large-scale disturbances.

Genetic Connectivity

This refers to the exchange of genetic material via larval dispersal, shaping evolutionary processes such as gene flow, adaptive potential and speciation. Genetic connectivity maintains genetic diversity, which is essential for adaptation to temperature stress, diseases and acidification.

Ecological Connectivity

This form includes the exchange of nutrients, organic matter, symbiotic organisms (e.g., Symbiodiniaceae), and interactions between species that move between habitats, such as herbivorous fish travelling between seagrasses, mangroves and reefs.

Physical Connectivity

Refers to the transport of larvae and materials by physical oceanographic processes including currents, tides, stratification, and eddies. Physical connectivity provides the framework upon which biological connectivity operates.

Understanding coral reef connectivity requires integrating all these dimensions to explain how reef ecosystems maintain structure, function and biodiversity across large geographical scales.

Ocean Currents as Vectors of Connectivity

Ocean currents are the primary drivers of larval dispersal, influencing both the direction and distance that coral and fish larvae travel. Currents exist at multiple spatial scales, each influencing connectivity differently.

Global Current Systems

Global and regional ocean circulation strongly shapes larval connectivity among coral reef systems. Large-scale currents such as the Indo-Pacific Warm Pool, Indonesian Throughflow, North and South Equatorial Currents, and the Gulf Stream link reef networks across entire basins and drive multi-year variability in larval dispersal. At intermediate scales, mesoscale eddies and gyres play a major role by either trapping larvae near their source reefs or transporting them long distances, especially in dynamic regions like the Coral Triangle. Along coastlines, seasonal current systems, monsoons, and tidal flows determine short-distance connectivity. In the Indian Ocean, for example, southwest monsoon currents push larvae westward, while northeast monsoon currents reverse the flow eastward, creating seasonal changes in recruitment patterns, spawning strategies, and dispersal pathways. Ocean stratification influences connectivity by forming layers with different current speeds. Larvae exhibit vertical migration behaviour to exploit these layers, thus altering dispersal outcomes.

Biological Drivers of Larval Transport

Larval transport in coral reef systems is strongly governed by species-specific biological traits that determine dispersal potential, survival, and settlement success. Pelagic Larval Duration (PLD) is a key factor, varying from a few hours in brooding corals, leading to highly localized dispersal, to several weeks in broadcast spawners. *Acropora* spp. typically show moderate PLDs of 4–14 days, while *Pocillopora* spp. exhibit extended PLDs of 20–50 days, enabling long-distance connectivity but increasing exposure to predation and starvation. Successful recruitment depends on larval competency and settlement cues, as coral larvae rely on chemical signals from crustose coralline algae, microbial biofilms, and reef-associated acoustic cues (e.g., snapping shrimp, feeding fish) to identify suitable substrates. Hence, connectivity involves not only physical transport but also the ability to detect and colonize optimal habitats.

Larval behavioural mechanisms further shape dispersal pathways. Vertical migration, phototaxis, and geotaxis help larvae regulate depth, exploit favourable current layers, and orient effectively within the water column. These behaviours reduce passive drift and enhance the probability of reaching reef environments. Together, PLD, settlement competency, and behaviour create a biologically driven framework that regulates coral larval dispersal and reef connectivity.

Source–Sink Dynamics in Coral Reef Networks

Coral reef ecosystems often operate as interconnected networks characterized by source and sink dynamics. Source reefs are those that produce an abundant supply of larvae that can disperse to other regions. Such reefs typically exhibit high fecundity, low levels of ecological disturbance, and hydrodynamic conditions that promote larval export. They often serve as reservoirs of biodiversity and genetic diversity. Sink reefs, in contrast, rely heavily on the influx of larvae from external sources to maintain their populations. These reefs are particularly vulnerable to disruptions in larval connectivity, as their long-term persistence depends on both the replenishment of coral populations and the maintenance of associated fish and invertebrate communities. Understanding the architecture of source–sink networks is therefore essential for informing conservation strategies and prioritizing reef protection efforts.

Connectivity and Coral Reef Resilience

Connectivity plays a foundational role in determining the resilience of coral reef ecosystems. Following disturbances such as cyclones, bleaching events, or predator outbreaks, reefs that receive a strong supply of larvae from neighbouring systems tend to recover more rapidly. This enhanced recovery is reflected in higher coral recruitment, reestablishment of herbivorous fish populations, and restoration of trophic structure. Connectivity also helps maintain genetic diversity by promoting the exchange of genetic material between geographically separated populations. This genetic flow contributes to increased thermal tolerance, disease resistance, and overall stress resilience. Ecosystem functioning is likewise reinforced through connectivity, as many ecological processes, such as nutrient cycling and herbivory, are supported by species maintained through larval dispersal.

Tools and Technologies for Studying Connectivity

Advances in molecular biology, oceanographic modelling, and environmental monitoring have substantially strengthened the study of reef connectivity. Genetic sequencing tools,

including mitochondrial DNA markers, microsatellites, SNPs, and whole-genome sequencing, enable researchers to infer both historical and contemporary patterns of gene flow among reef populations. Biophysical models integrate larval traits with high-resolution ocean circulation data to simulate dispersal pathways. These models incorporate spawning periods, larval behaviour algorithms, and three-dimensional current fields and have been widely applied in regions such as the Great Barrier Reef, the Coral Triangle, and the Caribbean.

Remote sensing and in situ oceanographic measurements complement these approaches. Satellite data provide information on surface currents, chlorophyll concentrations, thermal anomalies, and mesoscale eddies, while Acoustic Doppler Current Profilers (ADCPs) produce detailed vertical profiles of current velocity that improve model accuracy. Additionally, natural geochemical tags in coral skeletons or fish otoliths allow researchers to trace the natal origins of recruits based on elemental signatures.

Connectivity in the Context of Climate Change

Climate change is reshaping larval dispersal pathways and altering the connectivity of coral reefs. Shifts in monsoon patterns, gyre circulation, and upwelling intensity are changing the direction and strength of currents that transport larvae. Coral bleaching events reduce reproductive output, thereby limiting larval supply and weakening links between reefs. Ocean acidification can impair larval swimming ability and structural development, further reducing dispersal success. As sea temperatures warm, suitable coral habitats are moving poleward, generating new connectivity corridors while severing historical ones.

Connectivity-Based Approaches to Marine Protected Area Design

Connectivity science has significantly influenced modern Marine Protected Area (MPA) design. Contemporary MPA networks aim to incorporate source reefs, protect critical stepping-stone reefs that facilitate larval movement, and optimize spacing typically 20–50 km—to maintain ecological linkages. These networks also emphasize cross-boundary cooperation, particularly in regions like the Coral Triangle, where larval pathways traverse national borders. Case studies from the Great Barrier Reef, the Caribbean, and Southeast Asia demonstrate how connectivity modelling informs zoning decisions, enhances climate adaptation strategies, and strengthens regional biodiversity conservation.

Management Implications and Future Directions

Understanding connectivity is central to effective coral reef management. It informs the

identification of climate refugia, guides the selection of donor reefs for restoration, and helps predict vulnerabilities to population collapse when larval pathways are disrupted. Emerging research directions include the integration of reef microbiomes into larval settlement studies, development of models capable of predicting dispersal under extreme climate scenarios, and the use of acoustic mapping to identify previously unknown larval corridors. High-resolution global models represent a major future frontier in connectivity research.

Conclusion

Coral reef connectivity provides a unifying framework for understanding how reefs function as large-scale ecological networks. By integrating insights from physical oceanography, population biology, genetics, and conservation science, connectivity research reveals the mechanisms that enable reefs to persist despite environmental variability. As anthropogenic pressures intensify in the Anthropocene, maintaining and enhancing natural connectivity pathways will be critical for preserving coral reef biodiversity, ecological function, and resilience.

References

- Almany, G. R., Connolly, S. R., Heath, D. D., Hogan, J. D., Jones, G. P., McCook, L. J., ... & Williamson, D. H. (2009). Connectivity, biodiversity conservation and the design of marine reserve networks for coral reefs. *Coral reefs*, 28(2), 339-351.
- Ani, C. J., Haller-Bull, V., Gilmour, J. P., & Robson, B. J. (2024). Connectivity modelling identifies sources and sinks of coral recruitment within reef clusters. *Scientific Reports*, 14(1), 13564.
- Botsford, L. W., White, J. W., Coffroth, M. A., Paris, C. B., Planes, S., Shearer, T. L., ... & Jones, G. (2009). Connectivity and resilience of coral reef metapopulations in marine protected areas: matching empirical efforts to predictive needs. *Coral reefs*, 28(2), 327-337.
- Coelho, M. A., & Lasker, H. R. (2016). Larval dispersal and population connectivity in Anthozoans. In *The Cnidaria, Past, Present and Future: The world of Medusa and her sisters* (pp. 291-315). Cham: Springer International Publishing.
- Dickey, T., Lewis, M., & Chang, G. (2006). Optical oceanography: recent advances and future directions using global remote sensing and in situ observations. *Reviews of geophysics*, 44(1).



- Green, A. L., Maypa, A. P., Almany, G. R., Rhodes, K. L., Weeks, R., Abesamis, R. A., ... & White, A. T. (2015). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews*, 90(4), 1215-1247.
- Jones, G. P., Almany, G. R., Russ, G. R., Sale, P. F., Steneck, R. S., van Oppen, M. J., & Willis, B. L. (2009). Larval retention and connectivity among populations of corals and reef fishes: history, advances and challenges. *Coral reefs*, 28(2), 307-325.
- Raitsos, D. E., Brewin, R. J., Zhan, P., Dreano, D., Pradhan, Y., Nanninga, G. B., & Hoteit, I. (2017). Sensing coral reef connectivity pathways from space. *Scientific Reports*, 7(1), 9338.
- Thomas, C. (2015). Modelling marine connectivity in the Great Barrier Reef and exploring its ecological implications. *Ecole Polytechnique de Louvain*.

Volume: 05 Issue No: 12

SEA OTTERS AS CLIMATE GUARDIANS: HOW A KEYSTONE PREDATOR REVIVES KELP FORESTS AND LOCKS AWAY CARBON

Article ID: AG-VO5-I12-61

S. Bhaskar^{1*}, D. Manimekalai², Aparna A¹, Nazeela Barvin¹

¹Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu

²Assistant Professor, Department of Aquatic Environment Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu, India

*Corresponding Author Email ID: bhaskarsakthivelu@gmail.com

Abstract

Sea otters (species *Enhydra lutris*) serve as a classic example of a **keystone species** in coastal marine ecosystems. By preying on herbivorous invertebrates such as sea urchins and crabs, they regulate grazer populations, which in turn allows kelp forests and seagrass meadows to thrive. These vegetated marine habitats support high biodiversity, provide critical ecosystem services, and play a substantial role in carbon sequestration (so-called “blue carbon”). Recent studies indicate that the presence of sea otters can significantly boost carbon storage, enhance ecosystem resilience, and deliver economic as well as ecological benefits. A holistic perspective on why sea otter conservation matters for species, ecosystems, climate, and human societies.

Keywords: sea otter, *Enhydra lutris*, blue carbon, predator-mediated regulation, climate change mitigation

Introduction

Marine ecosystems are comprised of complex interactions among species, physical environment, and ecological processes. Among these, **top-down controls** where predators influence the abundance and behaviour of prey can dramatically shape entire communities. Sea otters exemplify this: though relatively small and not extremely abundant, their ecological influence is disproportionately large. Historically hunted almost to extinction for their fur, sea

otter populations plummeted, triggering cascading ecosystem changes. As conservation efforts have helped some populations recover, researchers have documented striking environmental and climate-relevant benefits tied to their presence. Understanding these benefits is critical in a time of declining biodiversity and accelerating climate change.

Here, how sea otters shape their environment, what data supports their role as ecosystem engineers, and why their conservation is not just about preserving a charismatic species but about protecting marine biodiversity, ecosystem services, and carbon-sequestering habitats.



The Ecological Role of Sea Otters

Sea Otters as a Keystone Predator and Trophic Cascade Trigger

- Sea otters predominantly feed on invertebrates such as sea urchins, crabs, mussels, and clams. Sea urchins are voracious grazers of kelp and other macroalgae. Without predators like sea otters, urchin populations can explode and overgraze kelp forests.
- By consuming urchins and other grazers, sea otters effectively curb grazing pressure, allowing kelp forests to persist and regenerate. This dynamic predator controls herbivore, herbivore controls primary producer is a textbook **trophic cascade**.
- The presence of sea otters therefore can toggle a coastal ecosystem between two alternate states: dense kelp forests vs. “urchin barrens” largely through predator-mediated regulation of grazers.

Effects on Kelp Forests, Seagrass, and Habitat Complexity

- Kelp forests benefit directly: when otters control urchin populations, kelp canopy cover, density, and biomass all increase.

- These kelp forests provide three-dimensional habitat shelter, food, breeding ground for fish, invertebrates, and other marine life, thereby boosting marine biodiversity and ecosystem productivity.
- In seagrass beds and estuarine environments, sea otters also contribute indirectly. By preying on crabs (that would otherwise prey on smaller grazers), otters help maintain a trophic balance that favours seagrass growth. This supports seagrass health and biodiversity.
- Kelp and seagrass ecosystems contribute to shoreline protection: they buffer wave energy, reduce erosion, and enhance resilience of coastal zones to storms and sea-level rise.

Carbon Sequestration and Climate Mitigation Data & Impacts

One of the most compelling aspects of sea otters' ecological role is their indirect impact on carbon dynamics, via the ecosystems they help sustain:

- Healthy kelp forests are powerful carbon sinks. Some studies estimate global seaweed forests (including kelp) sequester **tens of millions of metric tons of carbon annually** much of which is transported to deep-sea sediments, where it can be stored for centuries.
- Specifically, researchers have estimated that the presence of sea otters can increase carbon storage in kelp beds by **4.4 to 8.7 teragrams (Tg)** for a given sampled area, compared to similar regions without otters.
- According to a recent 2025 report, sea otters helping maintain kelp forests significantly contribute to climate change mitigation.
- Globally across their habitat range kelp ecosystems under protection by sea otters offer a “blue carbon” benefit, adding to the value of conserving these marine mammals.

In other words: Sea otters, by simply doing what they do naturally hunting urchins/crabs enable kelp forests and other vegetated marine systems to flourish, indirectly locking away large amounts of carbon and helping buffer climate change.

Evidence from Reintroduction and Recovery Case Studies

Recovery of Kelp Forests Following Otter Return

- A recent long-term study published in 2024 spanning a century of kelp-forest maps showed that as sea otter populations recovered along the California coastline, kelp forests expanded and became more resilient against environmental threats.

- According to the same study, otter reoccupation was the primary driver of kelp forest regrowth, more so than changes in substrate or bottom-up environmental factors.
- When sea otters return to coastlines where they had been absent, previously denuded “urchin barren” zones often shift back to lush kelp forests though the speed and magnitude of recovery can vary depending on local conditions and other species interactions.

Broader Ecosystem and Socioeconomic Benefits

- Studies estimate that with sea otters present, total ecosystem biomass (fish, invertebrates, kelp) increases significantly about **37% more biomass annually** compared to otter-less ecosystems. This translates into larger fish populations, improved biodiversity, better coastal protection, and enhanced carbon sequestration.
- Economically, regions with healthy sea-otter-maintained kelp forests benefit from **ecotourism, fisheries, carbon-sequestration value, and coastal protection**, often outweighing the reduced invertebrate fishery yields.

Challenges, Variability, and Context Dependence

Despite the clear benefits, the impact of sea otters is not uniform across all geographies or ecological contexts. Several caveats exist:

- The strength of the “otter → urchin → kelp” cascade depends on environmental conditions, substrate type, availability of alternative predators, and recruitment rates of urchins. In some regions, the recovery of kelp after otter return is slower or more limited.
- Human activity, such as fisheries targeting shellfish, recreation, and vessel traffic, can conflict with otter reintroduction or recovery affecting carrying capacity, disturbance levels, and habitat suitability. Such socio-ecological dimensions need careful management.
- The effectiveness of otter-driven carbon sequestration also hinges on long-term stability of kelp ecosystems. Environmental threats warming seas, pollution, ocean acidification still pose risks to kelp forests (and by extension to the benefits provided by otters).

Thus, while sea otters are powerful ecological allies, their success and the magnitude of their benefits depend on broader environmental, ecological, and human-management contexts.

Broader Significance: Sea Otters, Biodiversity & Climate Policy

The story of sea otters reflects a deeper principle: **protecting top predators can have**

cascading, large-scale benefits for biodiversity, ecosystem function, and even global climate regulation. Key takeaways include:

- Restoring or preserving keystone species is often more efficient and effective than piecemeal habitat restoration. As shown in otter–kelp systems, reintroducing or protecting a single predator can revive entire ecosystems.
- Sea otters showcase the value of “**nature-based solutions**” to climate and environmental challenges. By enabling blue-carbon ecosystems like kelp forests and seagrass beds, they contribute to carbon sequestration, coastal resilience, and biodiversity conservation.
- Economic incentives align with ecological ones. Healthy kelp forests support fisheries, tourism, and carbon-sequestration services; investing in otter conservation yields tangible human benefits alongside ecological integrity.

Conclusion

The small, often endearing sea otter is far more than a marine curiosity it is a cornerstone of coastal marine ecosystem health. Through predation on sea urchins and other grazers, otters enable kelp forests and seagrass meadows to flourish. These vegetated habitats in turn support rich biodiversity, stabilize coastal zones, and act as significant carbon sinks. Empirical data and real-world case studies show that sea otters help sequester carbon, boost ecosystem biomass, and enhance resilience against environmental stressors.

However, these benefits are not automatic: achieving them requires appropriate ecological conditions, careful management, and conservation policies that account for human interaction with coastal ecosystems. In an era of rapid environmental change and biodiversity loss, sea otters stand out as a powerful and relatively cost-effective lever for restoring ecological health and mitigating climate impacts. Protecting and reintroducing sea otters deserves to be a central component of marine conservation and climate-resilience strategies. Their return is not just a success for a single species it could be a win for ecosystems, climate, and humanity.

Volume: 05 Issue No: 12

STRENGTHENING INDIA'S FOOD GRAIN STORAGE: THE BACKBONE OF A SECURE AND SELF-RELIANT NATION

Article ID: AG-VO5-I12-62**Saikiran Chintakindi***

Assistant Professor, Dept. of Agril. Extension, Chaitanya Deemed to be University,
Hyderabad (T. S.). India.

*Corresponding Author Email ID: saikiran.52csk@gmail.com

Abstract

India's agricultural sector, one of the world's largest, plays a pivotal role in ensuring food security, generating employment, and supporting economic growth. Food grains comprising cereals, pulses, and millets form the foundation of the country's nutritional security, and efficient storage systems are essential for reducing post-harvest losses, stabilising prices, and maintaining year-round availability. India operates a multi-tiered storage framework involving centralized facilities managed by the Food Corporation of India (FCI), cold storages for perishables, and decentralized village-level storage through Primary Agricultural Credit Societies (PACS). FCI safeguards farmer incomes and maintains buffer stocks through procurement at Minimum Support Prices, storing grains in covered warehouses and steel silos, with a combined capacity of 917.83 LMT as of July 2025. Cold storage infrastructure, critical for perishables, has expanded to 8,815 facilities with 402.18 LMT capacity. PACS strengthen local procurement, reduce transit costs, and provide village-level storage, with 73,492 PACS computerized and 5,937 new PACS registered as of June 2025. Multiple government schemes support infrastructure development: the Agriculture Infrastructure Fund (AIF) has sanctioned ₹73,155 crore for 1.27 lakh projects; the Agricultural Marketing Infrastructure (AMI) scheme has sanctioned 49,796 projects with 982.94 LMT capacity; and PMKSY has enabled 1,133 completed projects with 255.66 LMT annual processing capacity. Additional support comes from cold storage subsidy schemes, the World's Largest Grain Storage Plan in the Cooperative Sector, and initiatives promoting steel silos, with 27.75 LMT already operational. Collectively, these systems and schemes strengthen

India's storage capacity, minimise post-harvest losses, and ensure a resilient and efficient food supply chain.

Key words: Food grain, post-harvest losses, storage systems and marketing infrastructure

Introduction

India's agricultural sector, one of the largest in the world, forms the backbone of the nation's economy by ensuring food security, generating employment, and supporting overall economic growth. Food grains, which make up the foundation of the human diet, include cereals such as rice and wheat, millets such as maize, jowar, and bajra, and pulses such as arhar, moong, urad, chana and masoor. Rich in carbohydrates, proteins, and essential nutrients, these grains are central to ensuring both food security and nutritional well-being in the country. India produces record harvests each year, and modern storage infrastructure helps preserve food grains and perishables by reducing post-harvest losses and stabilizing prices. By minimising wastage and extending the shelf life of produce, storage infrastructure strengthens the link between farms and markets, enabling farmers to secure better returns while supporting the growth of the food processing industry. For a growing nation with rising demand for raw and processed foods, efficient storage remains essential for maintaining year-round availability of essential commodities, securing buffer stocks, supporting the Public Distribution System (PDS), and ensuring that every grain contributes to national nutrition and economic progress.

The Importance of Food Grain Storage

Effective storage infrastructure plays a vital role in managing India's food supply chain, reducing wastage, and supporting the welfare of both farmers and consumers. Proper storage helps reduce post-harvest losses through the use of cold storage facilities and modern warehouses, ensures food security by maintaining sufficient buffer stocks for programmes under the National Food Security Act (NFSA), prevents distress sales by allowing farmers to store their produce until favourable market conditions arise, stabilises prices by maintaining strategic stocks, and preserves quality by controlling moisture, pests, and other factors. Together, these functions make storage a critical component of ensuring that food grains remain safe, accessible, and available throughout the year.

Food Grain Storage Systems in India

India uses multiple systems for storing food grains, including centralized storage managed mainly by the Food Corporation of India (FCI), cold storage for perishable

commodities such as fruits, vegetables, dairy products, and meat, and decentralized storage through rural godowns, Primary Agricultural Credit Societies (PACS), and on-farm storage at the village level.

A. Centralized Storage of Food Grains

The Food Corporation of India (FCI) serves as the primary agency responsible for centralized storage of food grains. Under the centralized procurement system, procurement for the Central Pool is undertaken either directly by FCI or by State Government Agencies (SGAs), which hand over the grains to FCI for storage and are reimbursed accordingly. FCI procures wheat, rice, and other grains at the Minimum Support Price (MSP) to safeguard farmers' incomes and maintain adequate buffer stocks. These stocks are stored in scientifically managed warehouses and steel silos to ensure quality and safety before being distributed through the Public Distribution System (PDS) or transported to states where additional stocks are required. As of July 1, 2025, the total Covered and CAP storage capacity available with FCI and state agencies for Central Pool food grains stands at 917.83 lakh metric tonnes (LMT). Covered storage refers to food grains stored in fully roofed structures such as godowns and warehouses, while Cover and Plinth (CAP) storage involves storing grains on elevated plinths with wooden crates used as dunnage.

B. Cold Storage Infrastructure

Cold storage infrastructure supports the preservation of perishables, including fruits, vegetables, dairy products, meat, and seafood. These facilities maintain freshness, quality, and nutritional value by providing temperature-controlled environments, which significantly reduce post-harvest losses. Cold chain infrastructure includes pre-cooling units, grading and sorting facilities, Controlled Atmosphere (CA) storage, blast freezers, packaging centres, and refrigerated transport systems such as reefer vans. The government provides substantial financial assistance for the creation of cold storage and cold chain projects through schemes such as PMKSY and AIF. As of June 30, 2025, India has 8,815 cold storages with a combined capacity of 402.18 lakh metric tonnes.

C. Decentralised Storage and the Role of PACS

Decentralised procurement, introduced in 1997–98, allows state governments to directly procure, store, and distribute food grains under the National Food Security Act (NFSA) and other welfare schemes. This system encourages local procurement, reduces transit costs, and ensures

the distribution of grains suited to regional preferences. Decentralised storage is largely carried out through Primary Agricultural Credit Societies (PACS), which operate at the village level as part of the cooperative credit structure. PACS provide loans to rural borrowers, recover repayments, and also handle procurement, storage, and distribution of food grains. By creating village-level storage facilities ranging from 500 MT to 2,000 MT, PACS help farmers store produce close to home, minimise losses, and secure better prices. PACS also serve as procurement centres and Fair Price Shops (FPS), reducing transportation needs and improving efficiency. To strengthen PACS operations, the government has approved a project to computerize operational PACS with a financial outlay of ₹2,516 crore. As of June 30, 2025, a total of 73,492 PACS have been computerized, and 5,937 new PACS have been registered.

Schemes for Strengthening Storage of Foodgrains

A. Agriculture Infrastructure Fund (AIF)

Launched in 2020, the Agriculture Infrastructure Fund (AIF) aims to strengthen agricultural infrastructure through medium- to long-term financing. The scheme provides interest subvention and credit guarantees for post-harvest management projects and farm-level assets, including warehouses, cold storages, grading units, and ripening chambers. These facilities help farmers store produce effectively, reduce losses, access wider markets, and realise better prices. As of September 2025, ₹73,155 crore has been sanctioned for 1.27 lakh projects under AIF, supporting infrastructure with a total project cost of ₹1.17 lakh crore.

B. Agricultural Marketing Infrastructure (AMI)

The AMI scheme, a major component of the Integrated Scheme for Agricultural Marketing (ISAM), focuses on strengthening agricultural marketing infrastructure by supporting the construction and renovation of godowns and warehouses. As of June 30, 2025, a total of 49,796 storage infrastructure projects have been sanctioned across 27 states, contributing to a combined capacity of 982.94 lakh MT, with ₹4,829.37 crore disbursed as subsidy.

C. Pradhan Mantri Kisan SAMPADA Yojana (PMKSY)

The Pradhan Mantri Kisan SAMPADA Yojana (PMKSY) aims to build modern infrastructure for the food processing sector, creating efficient supply chains from farms to retail markets. The scheme supports farmers by reducing wastage, improving price realisation, and promoting food processing and exports. A major component, the Integrated Cold Chain and Value Addition Infrastructure, helps establish cold chains to reduce post-harvest losses of

horticultural and non-horticultural produce. As of June 2025, 1,601 projects have been approved under PMKSY, with 1,133 projects already completed or operational, creating a processing and preservation capacity of 255.66 lakh MT per year.

D. Capital Investment Subsidy Scheme for Cold Storages and Horticulture Products

This scheme promotes scientific cold storage infrastructure to reduce post-harvest losses of perishables. It provides a credit-linked back-ended subsidy of 35% of the project cost in general areas and 50% in North-Eastern, hilly, and scheduled areas for constructing, expanding, or modernizing cold storages and Controlled Atmosphere facilities with capacities between 5,000 MT and 20,000 MT. The scheme helps farmers and entrepreneurs improve storage systems, increase shelf life, and secure better prices.

E. World's Largest Grain Storage Plan in the Cooperative Sector

Approved in May 2023, the World's Largest Grain Storage Plan in the Cooperative Sector aims to create Agri-infrastructure at the PACS level by converging schemes such as AIF, AMI, SMAM, and PMFME. Its objectives include promoting decentralized storage, ensuring year-round use of PACS godowns, improving the financial viability of PACS, and strengthening last-mile delivery. Under the pilot project, as of August 2025, construction of godowns has been completed in 11 PACS across 11 states, and more than 500 PACS have been identified for new construction.

F. Schemes for Augmentation of Storage Capacity

Under these initiatives, modern infrastructure such as steel silos is being constructed to support scientific storage and reduce post-harvest losses. Steel silos use bulk handling systems and controlled environments to extend shelf life and improve storage efficiency. As of June 30, 2025, silos at 48 locations with a capacity of 27.75 LMT are operational, while silos at 87 locations with a capacity of 36.875 LMT are under construction. Tenders for an additional 25.125 LMT at 54 locations are under process. Asset monetization efforts are also underway, with 177 FCI-owned locations identified where new godowns with a total capacity of 17.47 LMT can be built. The Central Sector Scheme "Storage & Godowns," focused on the Northeast, Himachal Pradesh, Jharkhand, and Kerala, has allocated ₹379.50 crore for the Northeast and ₹104.58 crore for other states. The Private Entrepreneurs Guarantee (PEG) Scheme, launched in 2008, further enhances storage by encouraging private investment through guaranteed hiring of storage facilities.



Conclusion

Agriculture remains the lifeline of India, feeding millions while sustaining livelihoods and driving economic growth. Although foodgrain production has reached record levels, efficient storage and distribution are essential to ensure that every grain reaches the consumer. The production and storage of food grains are fundamental to national food security, and with a growing population and a changing climate, maintaining adequate stocks, improving storage infrastructure, and reducing post-harvest losses are critical for ensuring year-round availability and price stability. Thus, food grains are more than agricultural outputs they form the backbone of agricultural growth, rural income, and global food systems.

VALUATION OF INTELLECTUAL PROPERTY RIGHTS

Article ID: AG-VO5-I12-63**¹Arathi, J., ^{2*}V. Krishnan, ²N. Swaminathan, ²V. Ramesh, ³M. K. Sakthi Anand**

¹ PG Scholar, ²Faculty & ²Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

The value of an IP is the value that the market places on licensing an IP or from sale or exchange of other intangible assets. The intangible assets of a company include goodwill, trademark, technological knowhow, trade secrets etc. The economic value of an asset is determined by market transactions between two unrelated entities dealing at arm's length. Unfortunately, intangible assets (including IP) seldom benefits from open market operations, either due to novelty or secrecy factors. Given the market conditions there is an urgent need to assess the economic value of such IP as early as possible in the product development cycle.

APPROACHES IN VALUATION OF IPR

Three basic approaches of valuation can be distinguished (Reilly & Schweih, 1998; Smith & Parr 2005):

- Cost approach
- Market approach and
- Income approach.

Each approach comprises several methods, which are based on the same valuation principle but differ in their individual application. Basically, every valuation method that can be found in literature, even if described as a “new method”, is more or less founded on one or a combination of several of these basic approaches. Figure 1 gives an overview of the valuation approaches and the mostly used valuation methods.

1. COST APPROACH

The cost approach seeks to measure the value of a good by quantifying the cost for the substitution of the asset by another. The basic assumption of this approach is that the cost to build or buy new property equals the value of its ownership (Smith & Parr, 2005). The reproduction cost method uses the cost of an exact replica, while the replacement cost method estimates the cost of the production or purchase of a good with an equivalent benefit. This means the asset must have the same utility but may be quite different in form and appearance. Because of the uniqueness of intellectual property an exact replica normally cannot be created. So, when using a cost approach, it is more appropriate to use replacement costs in this context.

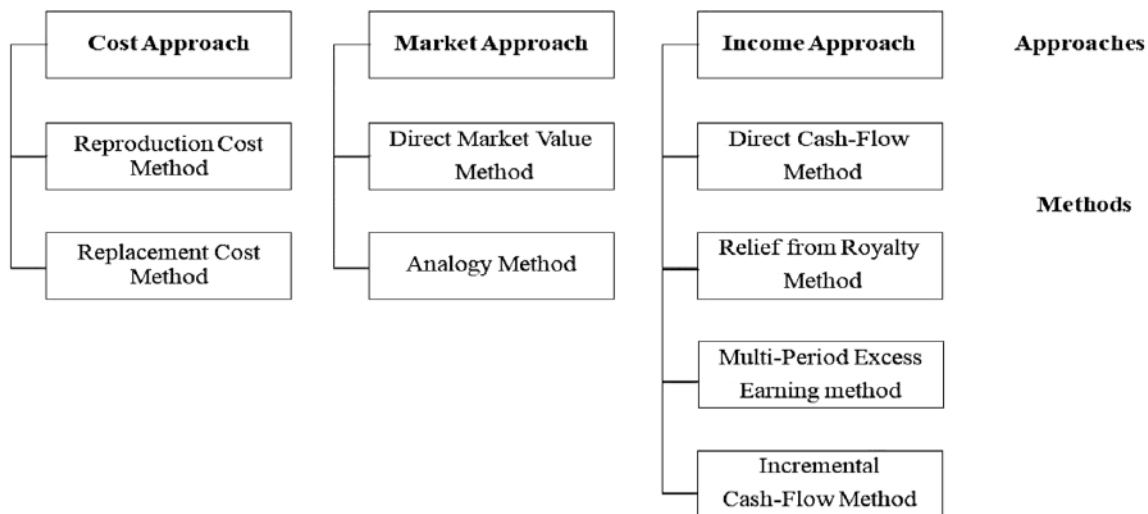


Fig. 1. Three different approaches in valuation of IPR

2. MARKET APPROACH

The market approach is based on paid prices as an indicator for the value of an asset. The underlying principle is that under certain conditions supply and demand lead to an equilibrium in competitive markets (Reilly & Schweihs, 1998). The direct market value method seeks to use directly regarded transaction prices for the subject asset. This method requires an active market for the good, which means that the traded assets have to be homogenous, willing buyers and sellers can be found at any time and prices are publicly known (IDW, 2007). Intellectual property normally cannot match these requirements. Thus appraisers try to find transactions with comparable assets and to transfer the paid prices to the valuation object. This is called the analogy method. When comparable transactions are found, a common denominator or yardstick has to be found in order to calculate a multiplier for transferring the regarded prices to the

appraisal object (Mard et al., 2000). Afterwards certain further adjustments can be necessary to take special market conditions, buyer motives or other distorting factors into account (IDW, 2005; Moser & Goddar, 2008).

3. INCOME APPROACH

The income approach to intellectual property (IP) valuation is based on the principle that the value of an asset is equal to the present value of the net economic benefits it will generate over its useful life. This method involves estimating the future cash flows derived from the IP, such as increased sales, cost savings, or licensing income, and discounting these cash flows back to their present value using an appropriate discount rate that reflects the investment's risk and opportunity cost (Smith & Parr, 2005; IDW, 2007). For example, a patent may provide cost savings or enable higher prices due to superior technology, or it may serve as a strategic barrier to competitors—both scenarios generating economic benefits. The core of the income approach is the discounted cash flow (DCF) method, where forecasted benefits over the asset's economic life are aggregated and adjusted for the time value of money. The discount rate represents the return required by investors as an alternative investment. Hence, the income approach values IP by quantifying expected future returns attributable solely to the IP asset and converting them into today's terms, providing a forward-looking and financially grounded measure of value. This method requires careful identification of the income specifically linked to the IP, an estimate of the duration of income generation, and a risk adjustment to reflect uncertainty in projections (Barton, 1998; Moser and Goddar, 2008).

Within the income approach different methods can be differentiated according to the way of determining the income flow (IDW, 2007):

- Direct Cash Flow Method,
- Relief from Royalty Method,
- Multiperiod Excess Earnings Method and
- Incremental Cash Flow Method.

i. Direct Cash Flow Method: This method values an IP asset based on the cash flows directly attributable to it. It works best when cash flows can be clearly measured, such as when the technology is licensed to third parties. For instance, Fraunhofer's mp3 technology generates significant license fees, which provide a reliable basis for valuation. The license fees represent

direct, quantifiable cash flows from the IP, making valuation precise especially for the near future.

ii. Relief from Royalty Method: This method estimates the value of owning the IP by calculating the royalties saved, which would otherwise need to be paid to license the same technology. It relies on observed license agreements of similar assets, making it partly market-based or even considered a hybrid approach. The challenges include availability and variability of licensing data, as different databases report diverse figures with limited contract specifics. Royalty rates are often estimated using rules of thumb, such as the 25% rule (licensor receives 25% of expected profits). Although simple, this rule is widespread in some industries. The method requires forecasting sales and costs, integrating valuation with business planning. The relief from royalty method, like the market approach, depends on the availability and quality of comparable licensing data but is generally more feasible since license rate data tend to be more abundant than purchase price data.

iii. Multiperiod Excess Earnings Method: This method values intellectual property (IP) by isolating the cash flows attributable to the IP from the total cash flow of a business unit. It does this by subtracting "contributory asset charges"—fictitious leasing fees for all other supporting assets used to generate income—from the total cash flows. These charges consider both the consumption of the asset's value and a reasonable return on capital employed. This method is complex due to the difficulty of appropriately quantifying these charges and should be reserved for IP that significantly impacts cash flows, where other assets are mainly supportive. While EBITDA or EBIT figures can be used for simplicity, direct cash flows are recommended to avoid double counting and improve accuracy.

4. INCREMENTAL CASH FLOW METHOD

This method values IP by comparing the cash flows of a business unit with and without the IP. The difference in cash flows represents the IP's contribution, which can arise from higher prices, increased sales, or cost savings. It requires reliable estimates of price, sales volume, and cost differences attributable to the IP, making it crucial to forecast these parameters accurately.

BENEFITS OF VALUE ASSESSMENT

Assessment of the value of IP provides certain benefits as well. Targeted valuation of IP helps companies to:

- Choose between market opportunities.
- More effectively protect and leverage the IP portfolio and important technology necessary to capture innovation and future growth.
- Develop a strategy for IP development and protection that is closely aligned with the company's overall strategic goals.
- Identify un-tapped value and revenue opportunities.
- Compare and select projects for the best allocation of the development budget.
- Better utilization of the IP portfolio through various commercial avenues such as licensing, donation, joint ventures, divestiture, transfer to suppliers, set-up of subsidiaries, spin-offs, *etc.*
- Justify a return on investment for technology and patents.
- Reflect overall company value more accurately on financial statements.

LIMITATIONS OF IP VALUATION

- It is based on estimates & assumptions, and a subjective bias.
- It is still a work in progress and hence would need some more time before companies can base economic strategies on it.

However, one should not see valuation as science, but an external judgment based on heterogeneous information pertaining to the IP, product and business project. Sound data and the scientific methodologies offer a scope for improvement. Because of the increasing importance of IP in a company's valuation, turning ideas into profit is and will continue to be the biggest challenge and the greatest reward of companies in the information age. Sensible decisions making an efficient allocation of resources are therefore essential in achieving the objectives.

OPTIMIZATION OF IPR BENEFITS AND WELFARE

Decisions made by managers are becoming increasingly critical in shaping the success or failure of modern businesses. As globalization, technological innovation, and complex regulatory frameworks reshape industries, business managers face heightened challenges in balancing profitability, legal compliance, and societal welfare. Business decisions are no longer confined to domestic constraints; they are shaped by global supply chains, international trade rules, intellectual property rights (IPR), and fast-changing consumer expectations.

A central theme in today's business environment is the role of intellectual property (IP)—patents, trademarks, copyrights, and trade secrets—in driving both innovation and competitiveness. Effective utilization of IPR not only strengthens a firm's market position but also ensures that the benefits of innovation are aligned with broader welfare considerations such as knowledge diffusion, fair pricing, and sustainable economic growth.

CONSTRAINED PROFIT MAXIMIZATION

Profit maximization continues to be a primary managerial goal, but it is inevitably subject to multiple external and internal constraints:

- **Resource scarcity:** With rising demand for rare earth minerals, clean energy technologies, and skilled human capital, resource allocation decisions are becoming more sensitive and pivotal.
- **Technology shifts:** Artificial intelligence (AI), automation, and green technologies are transforming the way firms produce and deliver value, requiring constant investment and adaptation.
- **Contractual obligations:** Strategic alliances, licensing agreements, and labour contracts often restrict the flexibility of firms, creating trade-offs between efficiency and compliance.
- **Regulatory obligations:** Firms operate under stricter frameworks such as data protection laws (e.g., GDPR), sustainability disclosure requirements, carbon neutrality regulations, and fair competition rules.
- **IPR compliance:** Protecting innovations while respecting international IPR laws is a growing challenge, especially when entering emerging markets where enforcement mechanisms may be weaker.

These constraints highlight the reality that strategic decisions are not made in a vacuum. Managers must weigh short-term gains against long-term sustainability, both in terms of profitability and societal impact.

OPTIMIZATION IN MODERN DECISION-MAKING

Optimization today involves more than simply equating marginal revenue and marginal cost. Businesses now integrate multi-dimensional objectives that balance profitability with welfare maximization. Modern optimization frameworks include:

- **IPR-driven optimization:** Firms strategically use patents and licensing to extract maximum financial value while promoting innovation diffusion through cross-licensing and open-source collaborations.
- **Sustainability-oriented optimization:** Managers increasingly optimize operations for energy efficiency, lower carbon footprints, and circular economy initiatives. Profit is maximized while also meeting sustainability targets.
- **Digital optimization:** Data analytics and AI-driven forecasting models allow managers to customize decisions at scale, improving accuracy in demand prediction, pricing, and inventory control.
- **Global welfare considerations:** Companies balance global IPR with affordable access (e.g., pharmaceuticals, green technologies). Optimizing here means creating value for shareholders while ensuring societal access to essential goods.
- **Resilience optimization:** Firms must constantly optimize for supply chain resilience amid geopolitical shocks, pandemics, and climate risks.

MATHEMATICALLY, OPTIMIZATION OF INTELLECTUAL PROPERTY:

The mathematical optimization of intellectual property (IP) can be represented as maximizing profit (π), defined as total revenue (TR) minus total cost (TC), subject to constraints including available resources, technology, intellectual property rights (IPR), and regulatory frameworks. Formally:

Maximize $\pi = TR - TC$

Here,

TR (total revenue) reflects the income generated from products or services that depend on technology, IP protections, and business operations and

TC (total cost) includes production, development, enforcement, and compliance costs related to those resources and constraints.

The constraints represent limitations and conditions under which firms must operate—such as availability of physical and human resources, technological capabilities, the legal scope and strength of IP rights protecting innovations, and market or government regulations. These factors evolve continuously with the dynamic market environment and legal frameworks and impact the feasible set of decisions for IP use and commercialization.

Optimization in this context aims to balance maximizing economic returns from exploiting IP assets while respecting legal protections and operational limits. Advanced mathematical methods, including differential equations and control theory, have been applied to model and optimize IP protection strategies, infringement dynamics, and enforcement intensity, providing theoretical guidance to minimize infringement and enhance innovation benefits under changing conditions (Wang, 2024).

In essence, this optimization framework helps enterprises to allocate resources and design strategies that maximize net returns from their IP portfolios within a complex legal and market landscape.

OPTIMIZATION OF IPR ASSETS

1. Optimal Price for a New Vaccine and Efficient Level of R&D

The optimization of intellectual property rights (IPR) assets, specifically regarding a new vaccine, involves determining an efficient level of R&D investment and setting an optimal vaccine price that balances social welfare and consumer benefits.

2. Efficient Level of R&D (x^*): The efficient R&D spending maximizes expected net benefits, considering uncertain outcomes of R&D efforts. The expected net benefit is:

$$\text{Expected net benefit} = q(x)/b - c - x$$

where:

b = average per person benefit of disease elimination,

x = per person R&D expenditure,

$q(x)$ = probability of successful vaccine discovery,

c = marginal production cost.

X^* , the efficient level of R & D, is the investment that maximizes this expected net benefit.

3. Pricing Criteria for Vaccine

i. Criterion 1: Social Efficiency Price: The price p is set equal to the average benefit b from the vaccine, ensuring that a profit-maximizing firm invests in the socially efficient level of R & D. At this price, the firm internalizes all benefits and costs, maximizing social welfare, but transfers all net social benefits to the supplier, resulting in zero consumer surplus.

- **Objective:** Maximize total social welfare, which includes the benefits to consumers and the profits of the vaccine developer (supplier).
- **Firm Behaviour:** A risk-neutral firm chooses R&D investment x to maximize expected profits

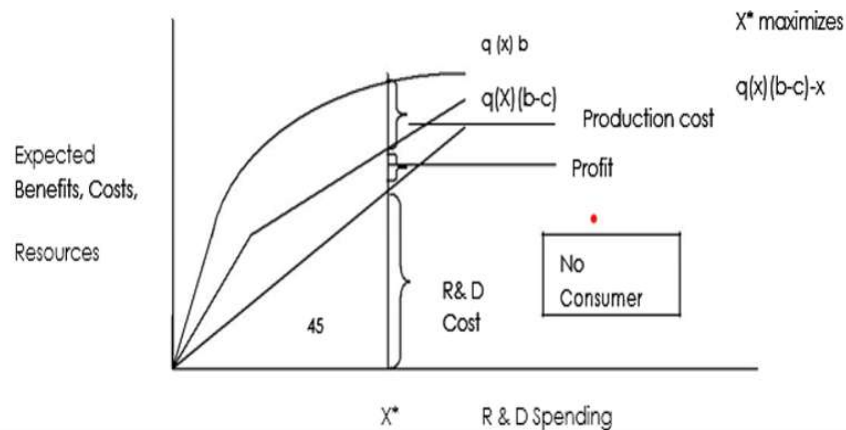


Fig. 2. Setting $p = b$ to maximize social welfare

:Expected profit= $q(x)/p-c/-x$

where p is the vaccine price, c is marginal production cost, and $q(x)$ is the probability of successful vaccine discovery.

- **Efficient Price:** To align the firm's profit-maximizing R&D level with the socially optimal R&D level (maximizing net social benefit), the price must equal the average per person benefit of the vaccine, $p = b$.
- **Implications:**
 - The firm internalizes all net social benefits and costs, providing correct incentives for optimal R&D investment.
 - Profits to the supplier capture all net social benefits, resulting in zero consumer surplus because the price is set at the full average benefit.
 - The planner does not need detailed information on production cost or research technology to set this price.
- **Drawbacks:** Social benefits are entirely transferred to the producer, which may reduce consumer welfare and raise equity concerns, especially in markets with income disparities.

ii. Criterion 2: Consumer Welfare Price: This represents the expected benefit to consumers as the difference between vaccine benefit b and price p , adjusted by the likelihood of vaccine availability $q(x)$.

- **Objective:** Maximize the welfare of vaccine buyers, focusing on consumer surplus rather than including producer profit.

- **Consumer Surplus Formula:** $cs = q(x)[b - p]$

- **Firm Behaviour:** The firm still maximizes its expected profit and chooses R & D investment according to:

$$q'(x)[p - c] = 1$$

where $q'(x)$ is the marginal increase in discovery probability from additional R & D spending.

- **Trade-Off:**

- Lowering the vaccine price p increases consumer surplus per unit but reduces firm expected profits, leading to less R&D investment x .
- Reduced R&D decreases the probability $q(x)$ that the vaccine is successfully developed.

- **Optimization:**

- The price and R & D level maximize consumer surplus subject to firm profit-maximizing behaviour.
- The optimal division of surplus satisfies the condition:

$$\frac{b - p}{p - c} = \frac{qq''}{(q')^2}$$

where q'' is the second derivative of $q(x)$.

- **Implications:**

- Price set below average benefit creates consumer surplus.
- Lower R&D investment reduces total social surplus compared to Criterion 1.
- Balances increased consumer welfare with incentives for innovation by factoring in the shape of $q(x)$, the probability function of successful research.

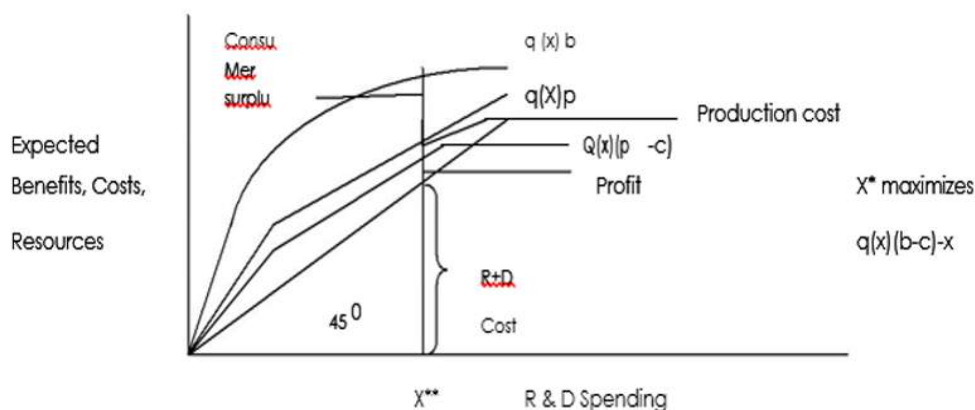


Fig. 3. Setting $p = b$ to maximize consumer surplus

Table 1. Comparison between Social efficiency and Consumer welfare

Aspect	Criterion 1 (Social Efficiency)	Criterion 2 (Consumer Welfare)
Price setting p	Equal to average benefit b	Below average benefit $p < b$
R&D Investment	Maximizes total social net benefit (x^*)	Maximizes consumer surplus, lower R&D (x^{**})
Producer Profit	Entire net social benefit transfers to producer	Producer profit reduced due to lower price
Consumer Surplus	Zero	Positive, due to price below benefit
Social Surplus	Maximized	Lower than Criterion 1 due to reduced R & D
Application Considerations	Efficient but may reduce consumer welfare and equity	Focuses on consumer welfare, trade-off innovation incentives

These criteria highlight the fundamental trade-offs between maximizing overall social welfare including innovation incentives and prioritizing consumer access and affordability. Policymakers must consider context, equity, and innovation dynamics when setting vaccine prices and supporting R & D.

WORLD INTELLECTUAL PROPERTY ORGANISATION

Article ID: AG-VO5-I12-64

¹*Krishnan, V., ¹N. Swaminathan, ¹V. Ramesh, ²J. Arathi and ³M. K. Sakthi Anand¹Faculty, ²PG Scholar & ³Ph. D. Scholar, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal 609603, U. T. of Puducherry, India

*Corresponding Author Email ID: anurathakrishnan66@gmail.com

Introduction

Intellectual property rights (IPRs) play a foundational role in modern innovation-driven economies by granting inventors or creator's exclusive economic rights, incentivising investment in research and creative activities, and promoting the public disclosure of technological advances for the benefit of society. As science and commerce have become increasingly globalised, effective protection and administration of IPRs now depend on coordinated action by multilateral organisations and national authorities. This section details the roles of the World Trade Organisation (WTO), the World Intellectual Property Organisation (WIPO), and India's national agencies in advancing, enforcing, and balancing IPR regimes worldwide.

THE ROLE OF THE WORLD TRADE ORGANISATION (WTO)

The WTO is the principal body governing international trade and, through the TRIPS Agreement (Trade-Related Aspects of Intellectual Property Rights), sets minimum standards for IPR protection among its members. The TRIPS Agreement, effective since 1995, is the most influential IPR treaty, covering copyrights, trademarks, geographical indications, industrial designs, patents (including plant varieties), integrated circuits, and trade secrets. It introduced three critical principles for IPR governance:

- **National Treatment:** This requires WTO members to extend the same IPR protection to foreign nationals as they do to their own citizens;
- **Most-Favoured-Nation (MFN):** Requiring equal treatment for nationals of all WTO members;

- **Minimum Standards:** Meaning every member maintains basic levels of IPR protection across all covered areas.

TRIPS also fosters balanced protection by permitting exceptions for public interest, including compulsory licensing for essential medicines or technology transfer to developing countries. The WTO provides a formal dispute resolution system to enforce compliance and curb discriminatory, anti-competitive, or trade-distorting licensing practices. These mechanisms help integrate IPR policy with broader global economic development and facilitate technology transfer across borders.

THE WORLD INTELLECTUAL PROPERTY ORGANISATION (WIPO)

WIPO is a specialised UN agency responsible for shaping global IPR policy by harmonising national laws, administering major international treaties, providing technical assistance, and maintaining global services for cross-border registration and protection. WIPO's major activities include:

- **Hosting forums and conferences:** To negotiate and develop international norms on IPR issues, including copyright, trademarks, patents, and geographical indications;
- **Administering 26 treaties:** Treaties such as the Patent Cooperation Treaty, Madrid Protocol, Budapest Treaty, and Marrakesh Treaty), which standardize registration and dispute resolution procedures across jurisdictions;
- **Assisting member countries:** With legal, technical, and policy support to modernise their IP offices and legislation;
- **Building databases:** Thereby publishing global IP statistics, and guiding research;
- **Promoting campaigns:** To raise awareness and encourage uniformity in national legislation.

WIPO's approach to IPR management is consultative and development-oriented, encouraging member states to adapt global standards according to their specific needs. Its dispute resolution services and technical capacity-building missions are vital for developing countries.

THE INDIAN PATENT OFFICE (IPO) AND POLICY INSTITUTIONS

India's national IPR administration falls under the Department for Promotion of Industry and Internal Trade (DPIIT), with the Indian Patent Office (IPO) overseeing patent, trademark, design, and geographical indication registration. India maintains a robust legislative and judicial infrastructure for IPR protection and enforcement, in line with TRIPS and WIPO conventions.

Recent initiatives include

- **The comprehensive National IPR Policy (2016):** This formalises objectives, streamlines awareness, strengthens legislative frameworks, improves enforcement, and builds human resources for IPR management.
- **Digitalisation of IP filings:** This favour faster grant and registration processes, and curricula reforms to foster IP literacy.
- **Innovative enforcement models:** For example, the Maharashtra IP Crime Unit, which integrates police and the private sector for anti-counterfeiting and piracy action.

India participates actively in WTO and WIPO negotiations, promotes balanced patent protection to safeguard public interest, and leverages international mechanisms (such as the PCT route for international patent filings) to support Indian innovators seeking global markets.

MULTILATERAL AND NATIONAL IPR AUTHORITIES

Effective global governance of intellectual property rights is therefore founded on the intersecting action of multilateral treaty systems and empowered national agencies. The resulting balance between incentives for innovation, protection of public interests, and the facilitation of cross-border technology transfer is central to sustainable development and the equitable diffusion of technological and creative advances in the 21st century.

Table 1. Core Functions of Multilateral and National IPR Authorities

Authority	Main Roles	Approach
WTO/TRIPS	Set baseline IPR standards, enforce compliance, resolve disputes, foster trade-IP linkages	Binding legal rules
WIPO	Harmonise laws, administer treaties, provide technical aid, and register international IP	Consultative, treaty-based
Indian IPO/DPIIT	Grant/Manage national IP rights, implement global norms, enforce legislation	National implementation

Multilateral Organisations in IPR

Multilateral organisations establish harmonised standards, resolve disputes, promote technology transfer, and coordinate enforcement mechanisms worldwide. The most influential organisations are the WTO (through the TRIPS Agreement) and WIPO, with national patent office such as the Indian Patent Office (IPO) implementing global and national policies.

Role of WTO in Protecting IPRs

The WTO, established in 1995, integrated IPR protection into the global trade system, primarily via the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS). TRIPS sets bindable minimum standards for patents, trademarks, copyrights, and trade secrets for all WTO member states.

Key Functions of WTO in IP Protection

- **Establishing minimum standards:** The TRIPS Agreement outlines the baseline for the protection and enforcement of IPRs globally.
- **Dispute Settlement Mechanism (DSM):** Ensures compliance through transparent and enforceable arbitration between states.
- **Integrating IPR with trade policy:** Recognises the interplay between trade and intellectual property protection.

India, as a signatory, has aligned its legislative framework with TRIPS. Recent revisions to Indian patent rules and rapid increases in granted patents exemplify compliance and robust enforcement.

FUNDAMENTAL PRINCIPLES OF THE TRIPS AGREEMENT

i. National Treatment

The principle of national treatment mandates that member states must provide foreign nationals the same intellectual property rights protections as they extend to their own citizens. This obligation prevents discrimination in both the protection and enforcement of IPRs, ensuring foreign inventors and rights holders receive equal treatment within a country. National treatment covers substantive protections as well as procedural aspects, such as the acquisition, maintenance, and enforcement of rights, enabling fair competition between domestic and foreign IP holders.

ii. Most-Favoured-Nation (MFN) Treatment

Most-Favoured-Nation treatment requires that any advantage, favour, privilege, or

immunity granted by a member to the nationals of one country must be immediately and unconditionally extended to the nationals of all other WTO members. This ensures that no member faces discriminatory treatment and promotes uniformity in international IP protection measures. MFN reduces transaction costs, facilitates trade liberalisation, and promotes equitable participation of all countries in the global IP system.

iii. Balanced Protection under TRIPS

While enforcing strong IP rights, TRIPS acknowledges the need for balanced protection that harmonises the interests of rights holders with broader public welfare concerns. This balance is achieved by incorporating important flexibilities such as compulsory licensing, which allows governments to authorise use of patented inventions without consent under certain conditions, and parallel importation, which permits importation of patented products marketed elsewhere at lower prices. These safeguards are especially crucial for developing countries to maintain access to essential medicines, agricultural inputs, and technology that support their socio-economic development.

iv. Curbing Anti-Competitive Licensing Contracts

TRIPS proactively addresses the potential misuse of IPRs through anti-competitive licensing practices. Articles 31 and 40 empower WTO members to legislate against licensing agreements that unduly restrain competition or impede technology transfer. Countries may adopt measures to prevent restrictive clauses such as exclusivity agreements or price-fixing that adversely affect market dynamics, ensuring that IP protection does not become a tool for market monopolisation or exclusionary practices.

v. Enforcement: Tough but Fair Approaches

The TRIPS Agreement mandates members to implement effective enforcement frameworks, encompassing civil, criminal, and border measures. The goal is to deter infringement, ensure timely remedies, and uphold due process, without creating unjustified trade barriers or allowing procedural abuses. The enforcement provisions require members to provide adequate remedies, including injunctions, damages, and seizures, while balancing the protection of rights holders with the rights of alleged infringers to a fair trial and appeal.

vi. Technology Transfer and Public Welfare under TRIPS

Recognising that intellectual property protection should contribute to technological progress and social welfare, Articles 7 and 8 of TRIPS promote technology transfer, especially to

developing and least-developed countries. The Agreement encourages members to implement policies facilitating the dissemination of knowledge, capacity building, and technical cooperation. These provisions underline the importance of IP systems that support public welfare objectives, such as health, environment, and food security, enabling countries to harness innovations for sustainable development.

vii. Transition Arrangements under TRIPS: Grace Periods for Compliance

Understanding varying development stages and capacities, TRIPS included transitional arrangements to facilitate effective compliance. Developed countries were required to comply immediately upon accession to the WTO. Developing countries were granted a grace period of five years to adjust their legislation and enforcement mechanisms. Least Developed Countries (LDCs) benefit from extended periods, often up to 10-11 years or more, to fully implement TRIPS standards. These transitional arrangements provide flexibility to build administrative, legal, and technical expertise essential for an effective IP system aligned with national development needs.

Table 2. Transition Periods under TRIPS

Country Type	Grace Period
Developed Members	Immediately (from 1995)
Developing Countries	5 years (until 2000)
Economies in Transition	5 years (subject to conditions)
Least Developed Countries	11+ years (with extensions possible)

WTO, IPR, AND HEALTH: THE PUBLIC HEALTH EXCEPTION

The World Trade Organisation (WTO) recognised through the Doha Declaration on the TRIPS Agreement and Public Health (2001) that public health protection must take precedence over private intellectual property rights. The Declaration clarified that the TRIPS Agreement does not and should not prevent members from taking measures to safeguard public health and ensure access to affordable medicines. Compulsory licensing and parallel imports are key flexibilities: compulsory licensing allows a government to authorise third parties to produce a

patented product or process without the consent of the patent holder, even in the absence of national emergencies. The August 30, 2003, WTO decision further improved access for countries with insufficient manufacturing capacity by allowing importation of generic medications produced elsewhere under compulsory license, with special provisions for least developed countries. The Doha Declaration has been instrumental in enabling countries, including India, to provide generic versions of patented medicines during health crises such as HIV/AIDS and COVID-19, ensuring health security while respecting international obligations.

IMPLEMENTATION OF IPRS IN DEVELOPING COUNTRIES

Implementing TRIPS has led many developing countries to modernise their intellectual property legislation and enforcement infrastructure. Benefits include increased foreign direct investment, access to advanced technologies, and stimulation of innovative activity. However, challenges persist—limited administrative resources, balancing domestic developmental and welfare needs, and potentially higher costs for essential goods due to stricter IP enforcement. Some developing countries lack the financial and technical capacity to meet TRIPS standards quickly, leading to requests for technical and legal assistance from WIPO and WTO. A gradual approach, along with transitional periods, has allowed these countries to devise strategies that align IP protection with broader social goals. Despite these supports, concerns remain regarding the rise in costs for medicines and agricultural inputs, especially where TRIPS-plus standards are enforced through bilateral trade agreements. ★ ★ ★ ★

POST-TRIPS EXPANSIONISM

After the TRIPS Agreement set minimum standards, developed nations began negotiating bilateral and regional agreements that require stricter IPR protections—described as 'TRIPS-plus' standards. These can include patent term extensions, data exclusivity provisions, and limits on the flexibilities allowed under TRIPS for public interest. TRIPS-plus agreements can reduce policy autonomy and make it harder for developing countries to protect public health, preserve access to knowledge, and encourage domestic innovation. The international community recognises the need to balance robust IP protection (which can stimulate investment and innovation) against equitable access, technology transfer, and development concerns. Multilateral forums such as WTO and WIPO continue to debate these issues, but many TRIPS-plus rules are promoted outside these organisations through bilateral or plurilateral treaties.

THE ROLE OF WIPO: CORE TASKS, MISSION, AND ACTIVITIES

WIPO (World Intellectual Property Organisation), as a United Nations agency, leads the development of balanced global IP systems. Its mission centres on promoting innovation and creativity through effective intellectual property protection. Its core functions include administering international treaties such as the Patent Cooperation Treaty (PCT), Madrid Protocol (trademarks), and Hague Agreement (industrial designs); facilitating the filing and prosecution of international IP applications; and acting as the global registry for patents, marks, and designs.

WIPO also plays a crucial role in developing international policy and legal standards for emerging technologies (such as artificial intelligence and genetic resources), delivers technical assistance and capacity-building to member states - especially to help developing nations build strong IP systems and provides global dispute resolution services via arbitration and mediation. Outreach efforts, like the WIPO Academy, promote awareness, education, and strategic use of IP by governments, businesses, and communities.

HOW WIPO WORKS

WIPO functions through diplomatic conferences and standing committees, allowing its 193 member states to draft, negotiate, and adopt new treaties. A typical WIPO diplomatic conference operates in plenary session and through specialised committees that handle substantive IP provisions, administrative procedures, and verification of delegates' credentials.

Table 3. WIPO Core Tasks and Activities

WIPO Activity	Example/Function
Treaty Administration	PCT (Patents), Madrid Protocol (Trademarks)
Global IP Services	International application/registration <i>via</i> PCT/Madrid
Policy Development	Standards for AI, genetic resources
Capacity Building	Training, technical assistance (WIPO Academy)
Dispute Resolution	International arbitration and mediation
Outreach/Public Awareness	IP education, materials, seminars

The organisation supports effective treaty negotiation, multilingual drafting, and technical alignment, with coordination by the Steering Committee. Adoption of a treaty does not immediately bind a country but signals a strong intent to participate. WIPO maintains global databases and provides technical services to national IP offices, facilitating global harmonisation.

The organisation works closely with WTO, especially regarding TRIPS implementation, collaborating on technical and legal assistance programs, and helping countries - primarily developing nations- adapt and enforce IP standards in ways that serve both national and global interests. WIPO supports treaty administration and capacity-building, while the WTO provides binding dispute resolution. TRIPS bridges both institutions, ensuring global IPR harmonisation.

Table 4. A comparison of WIPO, WTO and TRIPS

Organization	Primary Role	Treaties	Members	Enforcement	Governance
WTO	Trade-related IPR standards, dispute resolution	TRIPS Agreement	160+	Dispute settlement body	Ministerial conference
WIPO	IP policy, registration, capacity building	PCT, Madrid, Hague, others	190+	Soft (assistance/A DR)	Assemblies /Committees
TRIPS	Binding IPR standards for WTO states	Under WTO	WTO	WTO enforceable	Under the WTO Council

INDIAN PATENT OFFICE (IPO): STRUCTURE AND ACHIEVEMENTS

The Indian Patent Office, under the Controller General of Patents, Designs, and Trademarks, executes IPR grants nationally and participates in international processes. IPO has

modernised its examination process, enhanced e-filing and transparency, and significantly increased patent and GI (Geographical Indication) grants.

Recent Milestones

- In 2023-24, IPO granted over one lakh patents, the highest in its history.
- Streamlining of Patent Rules, introduction of “Certificate of Inventorship.”
- Tripling of GI registrations, celebrating India’s traditional knowledge.
- Expedited application processing, focus on innovation and investment climate.
- Major e-governance reforms, reducing pendency and increasing transparency.

PATENT APPLICATIONS THROUGH THE PCT ROUTE AND NATIONAL PHASE ENTRY

India is a member of the Patent Cooperation Treaty (PCT), administered by the World Intellectual Property Organisation (WIPO). This framework allows inventors and applicants to file a single international patent application designating multiple member states, including India. Following the international phase, which involves a search and preliminary examination, applicants can enter the “national phase”, where their application is examined under the domestic laws of India. The Indian Patent Office (IPO) plays a dual role—as a receiving office facilitating the filing of PCT applications—and as an examining authority overseeing substantive patent examination. This system provides Indian innovators efficient access to global patent protection while enabling international applicants to seek protection in India seamlessly.

ROLE AND FUNCTIONS OF THE NATIONAL INTELLECTUAL PROPERTY OFFICE (NIPO)

The National Intellectual Property Office (NIPO), operating under the Department for Promotion of Industry and Internal Trade (DPIIT), is the nodal policy body responsible for orchestrating India’s intellectual property framework. NIPO formulates national IP policies, coordinates legislative reforms, and manages India’s participation in international IP discussions and treaties. It acts as a vital conduit between international IP organisations and India’s national IP infrastructure, ensuring harmonisation with global standards.

THE NATIONAL INSTITUTE FOR INTELLECTUAL PROPERTY MANAGEMENT (NIIPM)

Located in Nagpur, the National Institute for Intellectual Property Management (NIIPM) delivers critical capacity-building services in intellectual property management. It organises

regular training sessions, workshops, and outreach programs designed for government officials, patent examiners, industry representatives, and academic stakeholders. NIIPM's role is pivotal in disseminating best practices, enhancing enforcement competency, and fostering a conducive ecosystem for innovation protection and exploitation throughout India.

AFFILIATIONS AND CAPACITY-BUILDING INITIATIVES IN INDIA

India maintains strong collaborative networks with academic institutions, research bodies, and industry associations that partner with IPO, NIPO, and WIPO to raise IP awareness and literacy. The National Intellectual Property Rights Policy of 2016 acts as a cornerstone, guiding systemic reforms including curriculum integration, promotion of strategic IP use, and the digitisation of traditional knowledge repositories. These coordinated efforts aim to cultivate a robust national IP culture that aligns with inclusive economic growth and increased global competitiveness.

Table 2.5. Key Multilateral and National Institutions in IPR

Institution	Core Functions	Mechanisms/Tools Used
WTO	IPR standards, compliance, dispute resolution	TRIPS, DSM, technical assistance
WIPO	Treaties, registration, policy, awareness	PCT, training, global IP databanks
Indian Patent Office (IPO)	Patent & GI granting, enforcement, modernisation	E-filing, PCT route, legal reform
NIPO/NIIPM	Capacity-building, R&D support, policy	Training, guidance, digital resources

Conclusion

The interplay of multilateral organisations, legal frameworks, and national agencies like IPO has transformed the governance of intellectual property in India and globally. WTO and TRIPS ensure minimum standards and enforceability, while WIPO fosters policy innovation and technical collaboration. India's reforms and milestones, underpinned by a growing culture of innovation, reflect the dynamic evolution of IPR governance as a tool for development, public welfare, and international competitiveness.

IMPACT OF BED CLEANING AND SPACING ON THE GROWTH AND HEALTH OF SILKWORMS (*BOMBYX MORI* L.)

Article ID: AG-VO5-I12-65

M. Parasuramudu*

*Post graduate, Department of Sericulture, Sri Krishna Devaraya University,
Anantapur-515003, Andhra Pradesh, India

*Corresponding Author Email ID: parasuram723b@gmail.com

Abstract

Efficient silkworm rearing depends greatly on the timely management of bed cleaning, spacing, and careful handling during moulting. Bed cleaning is essential to remove accumulated litter comprising unconsumed leaves, faecal matter, exuviae, and dead larvae, which otherwise promote microbial growth and create harmful microclimatic conditions. Different techniques such as the husk method, net method, and combined husk-net method are employed to ensure hygienic rearing beds with minimal larval injury and labour involvement. As silkworms grow rapidly, proper spacing must be provided to avoid overcrowding, ensure uniform feeding, and maintain optimal microclimate, while balancing the economic use of trays and mulberry leaves. Spacing schedules are generally aligned with bed cleaning operations for efficiency. During moulting, silkworms are highly sensitive and require special care, including maintaining dry beds, suspending feeding, and applying prophylactic measures such as lime powder or disinfectants like Suraksha and Vetcare Vijetha Supplement to prevent muscardine disease and promote uniform growth. Together, these practices play a vital role in enhancing larval health, minimizing disease incidence, and ultimately improving cocoon yield and quality in sericulture.

Bed Cleaning in Silkworm Rearing

Silkworm rearing involves maintaining a clean and hygienic environment for the larvae, as their growth and cocoon production largely depend on proper management practices. One of the most important hygiene measures is **bed cleaning**, which refers to the removal of accumulated wastes from the rearing trays.

Importance of Bed Cleaning in Silkworm Rearing

1. Prevents Disease Incidence

- Accumulated litter creates a damp and unhygienic environment favourable for the growth of pathogens such as fungi, bacteria, and viruses.
- Proper bed cleaning reduces the chances of diseases like flacherie, muscardine, and grasserie.

2. Improves Aeration

- Fresh air circulation is essential for healthy growth.
- Removal of litter prevents congestion and keeps the rearing bed light and aerated.

3. Reduces Bad Odour and Toxic Gases

- Decomposed leaves and faeces release harmful gases (like ammonia, carbon dioxide) which affect larval health.
- Bed cleaning keeps the rearing environment fresh.

4. Enhances Larval Growth and Uniformity

- A clean bed ensures that larvae get fresh, uncontaminated mulberry leaves.
- It supports uniform feeding, growth, and development of silkworms.

5. Prevents Mulberry Leaf Wastage

- Leftover, stale, and decayed leaves are removed, preventing them from mixing with fresh feed.
- This ensures larvae consume only nutritious leaves.

6. Improves Cocoon Quality and Yield

- Healthy larvae raised in clean beds produce good-quality cocoons with better weight, shell ratio, and reelability.

7. Facilitates Easy Handling

- Clean beds make it easier to feed, handle, and monitor larvae during the rearing process.

Frequency of Bed Cleaning

In principle, the rearing bed should be cleaned before every feeding to maintain maximum cleanliness. However, this is rarely practiced in the field, as frequent cleaning requires more labour and may also result in the accidental loss of young worms during handling. Young larvae, especially in the early instars, are delicate and highly susceptible to injury or stress during bed

cleaning. For this reason, a more practical cleaning schedule is followed, balancing labour economy with larval safety.

First instar: Cleaning is done only once, during the pre-moulting stage.

Second instar: Two cleanings are carried out — the first after moulting and the second just before the next moult.

Third instar: Cleaning is done three times — once after the moult, a second time in the middle of the stage, and a third just before the next moult.

Fourth and fifth instar: The cleaning frequency depends on the method of rearing. In shelf rearing, the bed is cleaned once every day, while in floor rearing, it is cleaned once during each instar.

This systematic schedule ensures that the rearing bed is kept clean enough to maintain healthy conditions, while also minimizing the risk of worm loss during handling.

Methods of Bed Cleaning in Silkworm Rearing

Maintaining cleanliness in rearing trays is essential for the health and productivity of silkworm larvae. Over time, various methods of bed cleaning have been developed to reduce labour, minimize injury to the worms, and improve efficiency. The main methods are as follows:

1. Cleaning with Husk

In this method, a thin and even layer of paddy husk is sprinkled over the rearing bed, usually before the first feeding in the morning. Freshly chopped mulberry leaves are then spread on the husk. The silkworms crawl upward through the husk layer to reach the leaves, leaving the waste material behind. At the time of the second feeding, leaves are spread in a clean tray, and the worms that have gathered on the top layer are gently transferred using a soft brush. The old litter, consisting of husk, faecal matter, and leftover leaves, is then removed from the previous tray.

Special notes:

- In the first two instars, powdered husk is preferred as it is easier for young larvae to move through.
- Recently, **charred husk** or **formalin-treated husk** is recommended, as these materials help suppress muscardine disease (a fungal infection).
- This method is effective but requires skill to handle worms gently without causing injury.

2. Cleaning with Net

This is one of the most widely adopted and labour-saving methods. A nylon or cotton net of

suitable mesh size is placed over the rearing tray. Freshly chopped mulberry leaves are then spread above the net. The silkworms crawl through the net's openings to reach the food. After the second feeding, the net is lifted and placed on a new tray, transferring the worms and leaves together, while the litter remains behind in the old tray.

Mesh size recommendations by instar:

- 1st & 2nd instars → 2 mm²
- 3rd instar → 10 mm²
- 4th & 5th instars → 20 mm²

Advantages:

- Simple to operate and less labour-intensive.
- Reduces direct handling of worms, minimizing injury.

Limitations:

- Not ideal when cleaning and spacing must be done simultaneously.
- Improper mesh size may either restrict worm movement (too small) or cause worms to fall through (too large).

3. Combined Net and Husk Method

This method incorporates the strengths of both husk and net cleaning. First, a thin layer of paddy husk is sprinkled on the bed, and a net of suitable mesh size is placed on top. Fresh mulberry leaves are spread on the net for two successive feedings. The worms crawl upward, gathering on the leaves above the net. Finally, the net along with the worms is shifted to a clean tray, while the husk and litter remain behind.

Benefits:

- Combines the **cleanliness of the husk method** with the **ease of handling of the net method**.
- Less skill is required compared to the husk method alone.

Drawbacks:

- More expensive than individual husk or net methods.
- Like the net method, it becomes inconvenient when spacing must be done together with cleaning.

4. Traditional Hand or Feather Cleaning

In some regions, the older method of cleaning is still in practice. Here, silkworms are manually removed from the dirty bed using a feather, chopsticks, or by hand, and then placed on a clean tray with fresh leaves. While simple, this method is **labour-intensive** and risky: worms are often injured, and many may be lost during the transfer process.

Spacing in Silkworm Rearing

Silkworms are fast-growing insects that undergo remarkable changes in size and weight during each larval stage. From hatching until the end of the fifth instar, the body weight of a silkworm increases **7,000 to 10,000 times**. This rapid growth makes it essential to provide adequate rearing space at every stage. The process of increasing the rearing area to match the growth and feeding requirements of the larvae is called **spacing**.

Importance of Spacing

Accommodates Rapid Growth

- During the **first instar**, larvae increase their weight about **15 times**.
 - In the **second and third instar**, growth multiplies by **4–5 times** each.
 - In the **fourth and fifth instar**, larvae grow nearly **25 times** in each stage.
- Without sufficient space, such growth cannot be supported, leading to poor larval health.

Prevents Overcrowding

- Crowded conditions restrict larval movement, feeding, and ventilation.
- This results in reduced leaf consumption, slower growth, and production of smaller, low-quality cocoons.

Improves Bed Hygiene

- Lack of space increases the accumulation of faecal matter, unconsumed leaves, and gases.
- This creates heat and fermentation in the bed, producing an unfavourable microclimate for the worms and predisposing them to diseases.

Ensures Economic Efficiency

- While overcrowding is harmful, excessively sparse spacing is uneconomical.
- Too much space increases the number of trays required, labour costs, and leaf wastage.

- Hence, the objective is to maintain *optimum spacing*, balancing worm health and resource use.

Practical Guidelines for Spacing

- In practice, silkworm rearers follow a systematic method of spacing at each stage:
- **From hatching to 3rd instar:** The rearing space should be doubled or tripled after every instar.
- **4th instar:** The space is increased by 2–3 times.
- **5th instar:** The space is again doubled.
- Overall, from hatching until the end of the 5th instar, the rearing space is increased **80–100 times**.
- This guideline is essential for rearers to decide the number of **disease-free layings (DFLs)** to rear within the available rearing house capacity.

Frequency and Methods of Spacing in Silkworm Rearing

Frequency of Spacing

- Frequent spacing demands excessive labour and disrupts the worms unnecessarily. In practice, spacing is done **once daily** or combined with **bed cleaning**, so that both operations are completed together. Importantly, **no spacing is given during the moulting period**, as the worms are inactive and vulnerable at that stage.

Methods of Spacing

- Spacing can be carried out either **independently** or **in combination with bed cleaning**:

Independent Spacing

- The rearing bed is extended by spreading fresh leaves or enlarging tray space.
- Worms from the thickest or most crowded portions of the bed are gently lifted and distributed evenly into less dense areas.
- This method is useful when the bed is too crowded but no cleaning is required.

Spacing Combined with Bed Cleaning

This is considered more convenient, as both operations are completed simultaneously.

- **Husk Method:** When husk is used for bed cleaning, worms are transferred as a group onto a fresh bed and then spread evenly with the help of feathers or chopsticks.

- **Net Method:** When net cleaning is used, the worms transferred onto the new tray are distributed as in independent spacing, ensuring uniform density.

Care during Moulting

Silkworms undergo **four moults** in their larval stage, as most commercial races are **tetramoulters**. Moulting is a sensitive period lasting **15–30 hours**, during which worms stop feeding and shed their old skin. Special care is necessary to avoid stress or disease during this stage.

Recognising Moulting Stages

- **Pre-moult:** Worms have a plump, shiny body and a smaller, darkened head. They move towards the bed periphery.
- **Moult:** Worms stop feeding, hold their body upright, and wriggle out of the old skin.
- **Post-moult:** Worms emerge with a larger head, soft and loose skin, and renewed appetite.

Management Practices

1. Before Moulting:

- When many worms show pre-moult signs, bed cleaning is done and wider spacing is provided.
- Leaves smaller than the standard size and in reduced quantity are given to maintain a relatively dry bed.
- Feeding is stopped once moulting begins.

2. During Moulting:

- Worms should **not be disturbed** as they shed their skins.
- To maintain dryness and prevent fungal diseases, lime powder is traditionally sprinkled on the bed.
- As an **antimuscardinic measure**, improved disinfectants have been developed:
- **Vijetha:** A dust formulation by CSRTI, Mysore. It reduces disease incidence and indirectly promotes larval growth and cocoon quality.

3. After Moulting:

- Feeding is resumed once all worms complete moulting.

- Late moulters, if present, are separated using a net and reared separately to maintain uniformity.

Conclusion

Proper management of bed cleaning, spacing, and moulting care is fundamental for the success of silkworm rearing. Regular removal of litter prevents the buildup of harmful microorganisms and gases, while systematic spacing ensures adequate feeding area and healthy growth of larvae. Careful handling during moulting, supported using disinfectants, helps maintain larval uniformity and reduces disease incidence during this sensitive stage. When these practices are followed scientifically and consistently, they create a hygienic rearing environment that promotes stronger larval development, higher cocoon yield, and superior silk quality, thereby ensuring both economic efficiency and sustainability in sericulture.

References

- Dandin, S. B., Basavaraj, H. K. and Suresh Kumar, N. (2005). Silkworm breeds and hybrids at Bangalore. Annual Report, CSR & TI, Mysore, p. 51.
- Kaviraj, M., Kumar, U., Chatterjee, S.N., Swain, S. L., Singh, M., and Nandi, K. (2021). Comparative performance analysis of mulberry silkworm (*Bombyx mori* L.) races for integration of superior yield and maximize profit in West Bengal.
- Krishnaswami, S., Kumararaj, S., Vijayaraghavan, K. and Kasiviswanathan, K. (1971). Silkworm feeding trials for evaluating the quality of mulberry leaves as influenced by variety, spacing and nitrogen fertilization. Indian Journal of Sericulture, 10, 79–89.
- Lakshmanan, S., Mallikarjuna, B., Ganapathi Rao, R., Jayaram, H. and Geetha Devi, G. (1998). Studies on adoption of sericultural innovations at farmers' level in Tamil Nadu: An Empirical Analysis. Indian Journal of Sericulture, 37(1), 44-47.
- Rajanna, B. H. (1999). Performance of silkworm, *Bombyx mori* L. on mulberry raised by using sericulture byproducts as manure. M.Sc. (Sericulture) Thesis, UAS, Bangalore, p. 105.
- Rathod, B. S., Nalwandikar P. K., Shetgar S. S., Sawant, C. G. and Sonkamble, M. M. (2015). Effect of feeding proportionately mixed mulberry leaves on double hybrid silkworm. International Journal of Life Sciences, 10(1), 1-4.
- Shankar, M. A. (1990). Nutritional management of mulberry and its effect on silkworm growth, development, and silk quality. Ph.D. (Agronomy) Thesis, UAS, Bangalore, p. 410.



- Benchamin KV, Jolly MS. “Principles of Silkworm Rearing.” Proceedings of the Seminar on Problems and Prospects of Sericulture. Vellore, India, 1986, 63–108.
- Buhroo, Zafar. Rearing Performance of Some Popular Bivoltine Silkworm (*Bombyx Mori* L.) Breeds during Spring Season, 2018.
- Chatterjee, Manojit, Nilay Ray. “Studies on Rearing Performances of Mulberry Silkworm (*Bombyx Mori* Linnaeus, 1758) in Hooghly District of West Bengal (India): A Newly Explored Area.” Acta Fytotechnica et Zootechnica, 2020, 23(2).
- Singh, Harjeet, Ravneet Kour. “Rearing Performance of Bivoltine Hybrids of the silkworm.” International Journal of Applied and Natural Sciences (IJANS), 2018:7:1–4.

Volume: 05 Issue No: 12

ENTERPRENEURIAL OPPORTUNITIES IN SERICULTURE

Article ID: AG-VO5-I12-66**PadmaPriya R., Pavithra N., Utchimahali T., Sabiya Sulthana M.,****Lokesh Kumar P and Basavaraj Somalingappa Purads**

Department of Sericulture, Forest College and Research Institute, TNAU,

Mettupalayam, Tamil Nadu, India

*Corresponding Author Email ID: priyaseenivasan0211@gmail.com

Abstract

The economic prosperity of a nation or region heavily relies on entrepreneurship, particularly in the context of the current unemployment crisis and the expected advancements in technology. The critical challenges in fostering entrepreneurship involve not only creating opportunities for entrepreneurs but also ensuring they receive the necessary support to achieve success. Cultivating mulberry plants, producing disease-free layings, rearing young (chawki) and mature silkworms for cocoon production, processing cocoons (silk reeling) for yarn manufacturing, spinning (including warp and weft production), wet processing (dyeing and printing), weaving (fabric creation), and both modern (computer-assisted) and traditional (textile design) marketing are just a few of the diverse activities that constitute the Indian silk industry. Furthermore, the products and by-products of sericulture have gained increasing importance in the biotechnological, pharmaceutical, and biomedical fields, particularly for developing high-value innovative products. Consequently, there is substantial potential for business development within the sericulture and seribiotechnology sectors. These opportunities empower young individuals and unemployed women to become successful entrepreneurs, contributing to the workforce while achieving self-sufficiency. This approach can address unemployment issues in both rural and urban areas of India, thereby improving socioeconomic standards.

Introduction

India's economy, identified as developing and boasting a GDP of USD 2.7 trillion, stands as the

sixth largest globally and is projected to grow at a quicker pace than other significant economies in the fiscal year concluding in March 2023. However, the country's unemployment rate of 8.3% and the jobless figures of 33 and 67 per thousand individuals in rural and urban regions, respectively, hinder its potential to become the world's leading economy. Consequently, promoting entrepreneurship development has been proposed as a viable strategy to tackle unemployment. Gorgievski and Stephan define an entrepreneur as an individual who initiates a new business and assumes the majority of the risks and profits that come with it. Entrepreneurs are also seen as valuable national assets essential for achieving optimal outcomes. To address this issue, the Indian government initiated the “Startup India” program, which focuses on fostering and supporting entrepreneurs in establishing a robust startup ecosystem and transforming India into a nation where citizens generate jobs rather than merely seek them.

The most advanced countries have emerged as “world leaders” due to their vision, creativity, research, and entrepreneurial spirit. As of February 28, 2023, the Department for Promotion of Industry and Internal Trade (DPIIT) has recognized 92,683 enterprises as startups registered under Startup India, significantly contributing to India's economic progress, as these entrepreneurs have further enhanced the nation's economic growth. The term “new entry” signifies entrepreneurship, which is generally achieved by launching a company that enables an individual or group to pursue a distinctive venture. To become an entrepreneur, one must have an in-depth understanding of the opportunities that arise for undertaking remarkable initiatives. An entrepreneurial opportunity, also known as a business opportunity, emerges when new products, raw materials, services, organizational strategies, and processes are utilized to market a product at a price exceeding its production cost.

The agricultural and industrial sectors present abundant entrepreneurial opportunities, especially in expanding economies like India, where agriculture and its allied sectors contribute 70% to GDP. Sericulture, commonly referred to as “silk farming,” is an intriguing business that involves the industrial cultivation of moth larvae to produce cocoons and silk for commercial purposes, covering both mulberry and non-mulberry sectors. The silk industry, one of India's oldest agro-based sectors, thrives particularly in rural areas where agriculture remains the main source of livelihood. India uniquely features a diverse sericulture system encompassing both mulberry and Vanya sericulture, spanning an area of 2,35,001 and 2,04,085 hectares, respectively. Over time, the sericulture industry has evolved from a long-term sustainable

business model to one heavily reliant on subsidies. Various enterprises such as Kishan Mulberry Nursery Plant, Grainages, Chawki rearing centers, Sericulture Equipment Supply Centers, Seri-Shops, Seri-clinics, and Seri-resource centers have emerged as distinct economic activities. Moreover, sericulture presents immense potential, offering a plethora of business opportunities ranging from basic to advanced sectors, including biomedical and pharmaceutical industries, known as the “Kalpavruksha,” where nothing is wasted from soil to fabric processes.

Furthermore, the sericulture sector's affiliation with 7.6 million job opportunities positions the post-cocoon industry as a center of employment openings. Hence, the sericulture sector is considered one of India's most established industries. The industrial goods and byproducts generated by this sector provide significant opportunities for entrepreneurs nationwide, and jobs in these companies rank among the best. The vast potential of sericulture attracts young individuals from across the globe to start their enterprises in this area. To identify business prospects that could improve our country and society, we analyze the most promising opportunities within the sericulture industry in this context.

Kisan Nursery

Mulberry primarily grows as a perennial crop, with the most prevalent propagation method involving the vegetative part of the plant, specifically the stem. However, mulberry farms encounter challenges in achieving uniform gardens due to the failure of cuttings to root, leading to gaps. Even if these gaps are filled with new cuttings or plants, the mulberry plants' growth will still be uneven. To address this issue and create uniform mulberry plantations, the practice of cultivating mulberry saplings has emerged in recent years. Recognizing the importance and value of healthy saplings, many farmers actively seek out strong saplings to initiate their mulberry plantations. The necessity to boost both the demand and supply of saplings has spurred the large-scale commercial production of saplings as a viable business opportunity. Additionally, recent research has confirmed that the returns and production costs for nursery saplings amount to Rs. 2.02 and Rs. 1.94 per sapling, respectively, in Karnataka and Andhra Pradesh. This indicates that starting a mulberry nursery to produce healthy saplings for sericulture farmers in need could be a highly profitable and successful business venture.

Mulberry as a business and industrial entity

Mulberry functions not only as a key food source for silkworms in silk and cocoon production but also possesses significant medicinal properties. The leaves and fruits of mulberry

are abundant in essential phytonutrients that promote health, including minerals, vitamins, phenolic compounds, fatty acids, carbohydrates, and amino acids. To harness these benefits, various industries around the world are manufacturing products derived from mulberry, including those in the food, beverage, herbal, cosmetic, and pharmaceutical sectors. Moreover, due to its significance in growth and metabolism, there is currently fierce competition among global manufacturers to create commercial items such as jams, lollipops, jellies, wines, syrups, functional beverages, meals, food colorings, and cosmetics. Notably, products like wine, jam, and mulberry fruits are highly coveted in developed countries like those in the West; therefore, India should increase its production of these items.

Grainage for silkworm grains

A saying suggests that "Grainages are the heart of Sericulture" and "the foundation of the Sericulture industry" due to their role in large-scale production of disease-free layings (silkworm eggs) to satisfy the needs of all sericulture farmers for cocoon production. As the second largest country in sericulture employment, India has a consistent demand for silkworm grains throughout the year. The demand for BV hybrid seeds was 89.08%, while MV x BV hybrids stood at 62.26%. Consequently, this business opportunity holds significant potential, enabling an investor to earn one rupee in net profit for each rupee invested. Furthermore, it has now developed a new division or primary business focused on producing Chitosan from the leftover pupal cuticle, pupal oil, and pupae as raw materials for creating poultry and fish feeds.

Silkworm pupa for oil

It's noteworthy that silkworm pupae are often overlooked in this country, even though their oil has various industrial applications, such as the production of biodiesel, cosmetics, soaps, animal feed supplements, surfactant development, and food processing. Approximately 75% of the unsaturated and polyunsaturated fatty acids present in silkworm pupal oil consist of alpha-linolenic acid (ALA), which comprises about 34.27% of the total. People have become increasingly aware of ALA's health advantages due to its capacity to reduce cholesterol levels, enhance memory, and act as an antioxidant that combats free radicals in the body. As a result, the oil derived from mulberry silkworm pupae through supercritical fluid extraction has shown a cost-benefit ratio of 1.57.

Commercial Chawkisilkworms production enterprise

The first and second instars of silkworms, often referred to as chawki worms, are

categorized as young or infant silkworms. Rearing these young silkworms using scientific methods is essential, as it enhances their strength and productivity, which ultimately influences the successful harvesting of cocoon crops. Consequently, chawki rearing demands specialized knowledge and expertise that many sericulture farmers lack, and most may not have the necessary equipment to cultivate young silkworms under optimal environmental conditions. To address these challenges, a significant number of sericulture farmers have begun depending on chawki rearing centers (CRCs) for healthy silkworm batches that guarantee successful cocoon yields. As a result, the cultivation of young silkworms has evolved into a business that provides employment opportunities for young individuals in rural areas and contributes significantly to their income. Currently, approximately 800 CRCs are registered throughout the country, according to amendments from the Central Silk Board 200632, encompassing both mulberry and non-mulberry sectors. Hence, it is recognized as one of the most lucrative and cost-efficient business ventures.

Cocoon production as an enterprise

Sericulture serves as a significant income-generating industry and plays a vital socio-economic role in the transfer and redistribution of wealth among communities, particularly benefiting the poorer sections. This venture is accessible to individuals from all backgrounds, including both landowners and those without land, as well as educated and uneducated people, demonstrating a cost-benefit ratio ranging from 1:1.52 to 1.59. Cultivating silkworms for the production of cocoons and silk has proven to be a consistently profitable and sustainable industry, which can be pursued even in areas facing drought, as it offers assured income within 30 to 40 days. Therefore, it is recognized as a promising and highly viable business opportunity for unemployed youth.

Cocoon Banks/Warehouses

In the northern regions of India, there are only two crops of cocoons harvested annually, with a significant gap between these rearing periods, resulting in a high demand for cocoons during the off-season among reelers. In contrast, the southern states produce an abundant supply of cocoons throughout the year, which leads to a decreased market demand and frequent drops in cocoon prices. This challenging scenario highlights the necessity for farmers to have access to storage facilities, which not all farmers can afford. To address this issue and prevent price crashes, establishing cocoon banks could benefit both reelers by providing a steady supply of

raw materials year-round and farmers by offering storage solutions during lean periods. Therefore, this idea presents an uncharted opportunity for entrepreneurs to create a cocoon bank as a viable and lucrative business.

Biocrafts and artisans

A new sector for adding value in sericulture is the creation of bio-crafts from pierced or sliced cocoons, which provides employment to individuals from lower socioeconomic backgrounds and enables them to achieve independence. Bio-crafts utilizing pierced or cut cocoons have carved out a niche market while also equipping women, rural children, and individuals with disabilities with new skills. The cost-benefit ratio of cocoon bio-crafts ranges from 1:1.27 to 1:5.54, suggesting it could be a profitable yet largely unexplored venture. Nevertheless, several non-governmental organizations are working to empower women through the creation and sale of impressive bio-crafts. Consequently, the production and promotion of biocrafts, which can serve as part of interior decoration, represent a promising business opportunity.

Silk's Biomedical Industry

Fibrin, often referred to as silk strand, along with sericin, known as gum, serve as the primary components of silk, both of which possess remarkable pharmacological and biological properties. Enzymatic or chemical methods are employed for their individual isolation. As noted by Lamboni et al. (2015), sericin finds applications in biotechnology for enhancing culture media and in biomedicine for purposes such as wound healing, cancer treatment, tissue engineering, and drug delivery. Concurrently, various biomaterials are being engineered using fibroin obtained through a reverse-engineering technique, including nanofibers, nanoparticles, nanocoatings, composite scaffolds, films, hydrogels, sponges, and microspheres. With the extensive applications of silk protein biomaterials in the healthcare industry, numerous companies are developing and commercializing these products; many are advancing through clinical trials, while a few remain in the research phase. Progress in biological sciences, engineering technologies, and, more recently, 3D printing is accelerating the application of silk fibroin matrices across different pharmaceutical and medical domains. Given the increasing importance of silk protein, entrepreneurs have the opportunity to utilize silk in creating various second-generation materials with potential applications and medical appropriateness.

Manufacturing of biofertilizers and biopesticides

In India, the bio-agriculture sector is the third largest within the biotech industry, primarily due to its production of biofertilizers and biopesticides, which is driving growth in the Indian agri-biotech market. The large-scale manufacturing of biofertilizers, biopesticides, and vermicomposting presents an opportunity for startups, as farmer-centric and participatory approaches to Integrated Farming System Management (IFSM), Integrated Nutrient Management (INM), and Integrated Pest Management (IPM) strive to promote environmentally friendly methods to maintain productivity and enhance resource use in sericulture.

Promotion of mechanization as a business

Given that sericulture is a labor-intensive industry, it is currently facing a shortage of workers, which highlights the need for **mechanization** to reduce production costs and ensure the sector's success. Consequently, this situation provides ample opportunities for business owners to innovate and supply appropriate machinery or tools to fulfill the requirements of seri-farmers. While established seri-farmers with stable finances may benefit from investing in such equipment, smaller-scale farmers often find it financially unattainable due to their unstable financial circumstances. If a business were to cater to this niche, it could prove to be a lucrative venture for an entrepreneur by offering these services to seri-farmers. A novel approach is being adopted in Andhra Pradesh, where women's self-help groups are facilitating the delivery of agricultural supplies directly to farmers through initiatives like Seri Poly Clinics or One Stop Shops. In these shops, they procure high-quality agricultural inputs at competitive rates, such as disinfectants, raising equipment, biofertilizers, biopesticides, newspapers, ropes, and other essentials, then resell these items to farmers with profit margins ranging from 10 to 20%. As these business models gain traction in other states with sericulture practices, they represent one of the most promising and profitable opportunities for aspiring entrepreneurs.

Silkworms as a host to produce cordyceps(mushroom) production

With a price of US\$ 2000 per kilogram, the cordyceps mushroom, which naturally grows on lepidopteran insects, is highly sought after in the United States. Due to its significant therapeutic benefits and rarity, commercial artificial cultivation methods have been established. Numerous small businesses in Korea produce Cordyceps in forms such as pupae or silkworm powder, which are utilized as dietary supplements or food ingredients to boost health. India presents an excellent opportunity for Cordyceps production due to its abundant supply of host

materials, with annual yields of approximately 139,162 MT of Mulberry, 18,660 MT of Tasar, and 5,782 MT of Muga fresh pupae.

Smartphone apps and disinfection units

In the silkworm rearing facility, disinfection is a routine practice employed to minimize the chances of pathogen recurrence. Seri-farmers implement disinfection methods to lower disease occurrence during silkworm cultivation, relying on their experiential knowledge and practices. However, small-scale farmers face specific challenges due to insufficient funds to acquire proper equipment and challenges in preparing disinfection solutions using basic and inconsistent measurements. Consequently, there is a considerable reduction in cocoon yield caused by inadequate disinfection and the resurgence of diseases affecting silkworms. SeriApp is a mobile application developed to help overcome these challenges and ensure effective disinfection. Therefore, creating a versatile mobile application that provides appropriate guidance to seri-farmers based on scientific advice, alongside a mobile disinfectant and supplementary tools, would be a lucrative venture in the sericulture business.

Conclusion

The nation is currently grappling with unemployment challenges, particularly in both rural and urban settings. Consequently, the Indian government has introduced six key initiatives – the Startup India Scheme, the Mudra Yojana Scheme, the Stand-Up India Scheme, the Atal Innovation Mission (AIM), the Electronic Development Fund (EDF), and the Pradhan Mantri Mudra Loan Yojana (PMMY). Given the significant benefits these flagship programs offer, including tax exemptions, simplified compliance through self-certification, and a dedicated mobile application for registration, aspiring entrepreneurs can now establish businesses ranging from basic sericulture roles to cutting-edge biotechnological and biomedical industries focused on producing high-value silk protein products. In this context, the sericulture sector is experiencing a transformation driven by advanced technology, automation, and improved supply chain management. This evolution is generating numerous opportunities for new business ventures, job creation, and overall economic growth. To support these efforts, innovative programs like “Startup India” have established a framework for nurturing a new generation of entrepreneurs capable of empowering themselves while making a significant contribution to addressing India's unemployment challenges.

References

- Borah, P. (2019). A brief study on the entrepreneurship in North East India with special reference to Assam. *Critical Reviews*, 6(1), 118–126.
- Casson, M. (1982). *The entrepreneur: An economic theory*. Barnes & Noble Books.
- Davidsson, P. (2015). Entrepreneurial opportunities and the entrepreneurship nexus: A re-conceptualization. *Journal of Business Venturing*, 30(5), 674–695.
- Gorgievski, M. J., & Stephan, U. (2016). Advancing the psychology of entrepreneurship: A review of the psychological literature and an introduction. *Journal of Applied Psychology*, 65(3), 437–468.
- Mali, D. D. (2000). *Promoting new entrepreneurs*. Indian Institute of Entrepreneurship.

Volume: 05 Issue No: 12

FUTURE OF AGRICULTURE IN INDIA: RESOURCES, COMMUNITIES, CORPORATE DYNAMICS, AND THE ROLE OF ARTIFICIAL INTELLIGENCE

Article ID: AG-VO5-I12-67**Mr. B. Muthuraja**

Professor (Agricultural Economics)

PGP College of Agricultural Sciences, Namakkal, Tamil Nadu – 637405, India

*Corresponding Author Email ID: muthurajavijay@gmail.com

Abstract

India's agricultural sector sustains more than half of its workforce while feeding a population projected to exceed 1.6 billion by 2050. Rapid urbanisation, climate variability, dwindling natural resources, and advances in digital technologies are converging to reshape the agrifood system. This paper analyses the probable trajectory of Indian agriculture over the next three decades, focusing on (i) the status and future of critical resources (land, water, energy, and inputs); (ii) the socio-economic implications for small-holder farmers; (iii) the emergence of corporate farming and market-oriented supply chains; and (iv) the prospective displacement or augmentation of human labour by artificial intelligence (AI) and robotics. By weighing the anticipated benefits against the attendant risks, the essay proposes a set of evidence-based policy measures for the Government of India to steer a resilient, inclusive, and sustainable agricultural future.

Keywords: Indian agriculture; Resource sustainability; Smallholder farmers; Corporate farming; Agrifood supply chains; Artificial intelligence; Precision agriculture; Agricultural labour; Digital agriculture policy; Climate resilience

1. Introduction

Agriculture remains the backbone of the Indian economy: it contributes about 17 % to Gross Domestic Product (GDP) and employs roughly 42 % of the total workforce (Ministry of Agriculture & Farmers' Welfare, 2023). Yet the sector faces multiple, inter-linked challenges—fragmented land holdings, over-extraction of groundwater, climate-induced yield volatility, and a

widening productivity gap with major exporters such as the United States, Brazil, and the European Union (FAO, 2022).

Concurrently, digital transformation is accelerating. According to the National Institution for Transforming India (NITI Aayog), the country's agritech market is expected to reach US\$24 billion by 2025, driven by AI-based advisory services, satellite-enabled precision farming, and autonomous farm equipment (NITI Aayog, 2022). These developments raise profound questions: Will resource constraints force a shift toward large-scale corporate farms? How will the large cohort of smallholders adapt to AI-mediated decision-making? What are the socio-economic trade-offs of a technology-heavy agrifood system?

This essay offers a comprehensive analysis of these issues, integrating scholarly literature with recent newspaper and policy reports. **It concludes** with a set of actionable recommendations for the Government of India to harness technology while safeguarding the livelihoods of its farming community.

2. Current Landscape of Resources

Scarcity of water and land, coupled with rising energy costs, will force a re-allocation of resources toward higher-value, resource-efficient cropping systems and technology-enabled precision management.

Resource	Current Status	Projected Trend (2025-2050)	Key Drivers/Constraints
Land	Net cultivated area ~ 155 million ha ($\approx 52\%$ of total land). Average farm size 1.2 ha; 86 % of holdings < 2 ha (MoA, 2023).	Slight contraction ($\approx -3\%$ by 2050) due to urban sprawl, industrialisation, and conversion to non-agricultural uses (World Bank, 2021).	Land-use policy, real-estate pressure, land-fragmentation, lack of consolidation mechanisms.
Water	80 % of irrigation relies on groundwater; > 250 km ³ extracted annually—exceeding recharge in several basins	Decline of 20-30 % in groundwater levels in major aquifers (e.g., Punjab, Haryana) by 2050 (NITI Aayog, 2022).	Over-extraction, climate-induced rainfall variability, inefficient irrigation (e.g., flood irrigation).

Resource	Current Status	Projected Trend (2025-2050)	Key Drivers/Constraints
	(CGWB, 2022).		
Energy	60 % of farm electricity supplied via subsidised grid; high diesel consumption for mechanisation.	Shift toward renewable-based power (solar pumps) – projected 40 % of irrigation energy from solar by 2030 (IEA, 2023).	Subsidy reforms, declining solar PV costs, grid reliability.
Inputs (Seeds, Fertiliser, Pesticides)	70 % of seed market dominated by multinational corporations; 50 % of fertiliser consumption is nitrogen (N) (ICAR, 2023).	Gradual adoption of bio-fertilisers and climate-resilient seeds; potential 15 % reduction in synthetic fertiliser use by 2040 (FAO, 2022).	Regulatory approvals, farmer awareness, price incentives.

3. Impact on the Farming Community

3.1 Demographic Shifts

- **Aging Farmer Population:** The average age of Indian farmers is 48 years, rising from 45 years in 2010 (CSI, 2022). Younger generations are increasingly reluctant to continue farming due to low profitability (The Hindu, 2023).
- **Rural-Urban Migration:** Rural-to-urban migration has accelerated, with an estimated 12 million workers leaving agriculture annually (World Bank, 2021). This outflow reduces labour availability for labour-intensive crops (e.g., pulses, oilseeds).

3.2 Economic Viability

- **Yield Gaps:** Despite a 30 % increase in average yields for cereals since 2000, India still lags behind the global average by 25 % (FAO, 2022).
- **Profitability Index:** Farm-gate price volatility, high input costs, and limited access to credit keep the profitability index below 1.0 for 70 % of smallholders (Economic Times, 2023).

3.3 Social Consequences

- **Debt Distress:** Farmer suicides, linked to indebtedness, persisted at an average of 8,000 per year between 2018-2022 (NDTV, 2023).
- **Gender Disparities:** Women constitute ~45 % of agricultural labour but own < 5 % of land (World Bank, 2022). Technological adoption may exacerbate gender gaps if not inclusive.

Without targeted interventions, the resource squeeze and market pressures are likely to increase farm consolidation, marginalise smallholders, and deepen rural distress.

4. Rise of Corporate Farming and Market-Oriented Supply Chains

4.1 Definition and Scale

Corporate farming refers to large-scale, capital-intensive operations owned by agribusiness firms, often integrated vertically (seed → input → production → processing → retail). In India, corporate involvement is evident in:

- **Contract Farming:** Over 2 million ha under contract with private firms (Mahindra & Mahindra, 2022).
- **Supply-Chain Integration:** Retail giants such as Reliance Fresh and BigBasket now source directly from farmer clusters, bypassing traditional mandis (The Economic Times, 2023).

4.2 Drivers

- **Policy Incentives:** The 2020 Farm Laws (later repealed) emphasized “farm-gate sales” and “agri-business” investments, signalling a regulatory shift (Press Information Bureau, 2020).
- **Technology Adoption:** AI-driven yield prediction, blockchain traceability, and drone-based scouting lower transaction costs and enhance market access (Kumar et al., 2022).

4.3 Potential Outcomes

Positive	Negative
Scale Economies: Lower per-unit input costs, improved access to credit and insurance.	Land Concentration: Smallholders risk displacement or become wage labourers.
Quality Standards: Uniform grading, better	Market Power: Corporates may dictate

Positive	Negative
post-harvest handling reduces wastage (10 % loss vs. 20 % in traditional supply chains) (NITI Aayog, 2022).	prices, eroding farmer bargaining power.
Export Competitiveness: Ability to meet international phytosanitary standards.	Data Monopoly: Proprietary AI platforms could lock farmers into subscription models.

4.4 Empirical Evidence

A longitudinal study of contract sugarcane farms in Maharashtra (Patil & Sinha, 2021) showed a 22 % increase in farmer income over five years, but also a 15 % rise in labour-intensity for non-contracted workers, indicating uneven benefits.

5. Artificial Intelligence, Robotics, and the Future of Labour

5.1 Current AI Applications

Application	Description	Adoption Rate (2023)
AI-Based Advisory (e-Kisan, mKisan)	Mobile platforms provide weather forecasts, pest alerts, and optimal sowing dates using machine-learning models.	12 % of cultivated area.
Precision Irrigation (Smart Drip, Soil-Moisture Sensors)	Sensors transmit real-time data to cloud-based controllers that adjust water delivery.	5 % of irrigated farms (CGWB, 2022).
Drone Scouting & Spraying	UAVs map crop health and apply pesticides selectively.	Pilot projects covering ~ 1 % of high-value horticulture (India Today, 2023).
Autonomous Tractors	Semi-autonomous tractors equipped with GPS and AI navigation.	Limited field trials; < 0.5 % of mechanised land.

5.2 Prospective Displacement vs. Augmentation

- **Displacement:** Studies suggest that complete mechanisation of labour-intensive crops could reduce agricultural employment by up to 15 % by 2040 (ILO, 2022).

- **Augmentation:** Conversely, AI can create “digital agronomist” roles, demanding data-analysis, equipment maintenance, and advisory services—skills that can be upskilled locally (Kumar & Singh, 2022).

5.3 Risks

- **Digital Divide:** Rural broadband penetration stands at 45 % (TRAI, 2022); low connectivity hampers AI adoption among marginal farmers.
- **Data Privacy:** Absence of robust agridata protection laws may expose farmers to exploitation (BBC News, 2023).

5.4 International Benchmark

The United States’ “Smart Farming” initiative (USDA, 2021) estimates a net gain of 30 % in labour productivity while maintaining overall employment through new service sectors. India’s lag in digital infrastructure suggests a need for concerted policy action to replicate such outcomes.

6. Pros and Cons of the Projected Agricultural System

6.1 Advantages

1. **Resource Efficiency** – Precision irrigation can cut water use by 30-40 % (CGWB, 2022).
2. **Higher Yields & Quality** – AI-guided nutrient management can raise wheat yields from 3.2 t/ha to 4.0 t/ha (ICAR, 2023).
3. **Market Transparency** – Blockchain traceability reduces adulteration, enabling premium pricing for organic produce (The Hindu Business Line, 2023).
4. **Climate Resilience** – Climate-smart varieties and predictive analytics help mitigate extreme weather impacts.

6.2 Disadvantages

1. **Capital Intensity** – High upfront costs for AI hardware and corporate infrastructure may widen the gap between affluent and marginal farmers.
2. **Employment Loss** – Mechanisation may displace seasonal labour, exacerbating rural unemployment unless alternative livelihoods are created.
3. **Concentration of Power** – Data ownership by a few agritech firms could erode farmer autonomy.
4. **Ecological Risks** – Over-reliance on inputs generated by AI (e.g., nitrogen optimisation) may still lead to soil degradation if not coupled with regenerative practices.

7. Policy Recommendations

Policy Domain	Specific Measures	Rationale & Expected Impact
Resource Management	- Enforce a <i>Water-Use Efficiency</i> (WUE) mandate – minimum 70 % WUE for all new irrigation schemes. - Implement a <i>Land-Bank</i> system to facilitate voluntary pooling of fragmented holdings for lease to cooperatives.	Improves water sustainability; enables economies of scale without forced land acquisition.
Financial & Credit Support	- Create <i>Green Credit</i> lines with lower interest for farms adopting AI-enabled precision tools (e.g., sensor kits). - Establish a <i>Farmer Digital Literacy</i> grant to subsidise smartphones and internet connections.	Reduces cost barrier; promotes inclusive digital adoption.
Regulation of Corporate Farming	- Mandate <i>Benefit-Sharing Agreements</i> in contract farming – minimum 30 % of net profit to be allocated to farmer-owned cooperatives. - Enforce <i>Antitrust Review</i> for agritech mergers exceeding a 30 % market share in a commodity.	Protects smallholder interests; prevents monopolistic control of data and markets.
AI & Data Governance	- Enact a <i>Personal Agricultural Data Protection Act</i> (PADPA) modelled on GDPR, ensuring farmer consent and data portability. - Set up a <i>National Agritech Innovation Hub</i> under NITI Aayog to foster open-source AI models.	Safeguards privacy; encourages competition and local innovation.
Skill Development & Employment	- Launch a <i>Rural Tech-Upskilling Programme</i> (RTUP) delivering certifications in drone operation, agronomic data analytics, and equipment maintenance. - Provide <i>Public Works</i> contracts for agro-forest restoration to absorb displaced farm labour.	Generates new jobs; aligns labour supply with emerging agritech demand.
Research & Extension	Increase ICAR's budget by 25 % to accelerate climate-resilient seed breeding	Strengthens evidence-based farming; improves adoption

Policy Domain	Specific Measures	Rationale & Expected Impact
	and low-input agro-ecological practices. • Deploy <i>Digital Extension Officers</i> in every district to bridge the gap between AI platforms and field realities.	rates.
Market Infrastructure	• Upgrade rural cold-chain capacity to 50 % of current requirements by 2030. • Institutionalise <i>e-Mandis</i> with real-time price discovery, linked to blockchain verification.	Reduces post-harvest losses; empowers farmers with price information.

Conclusion

India stands at a crossroads where resource constraints, demographic change, and rapid technological diffusion intersect.

References

- Central Ground Water Board. (2022). *Dynamic groundwater resources of India*. Ministry of Jal Shakti, Government of India.
- Centre for the Study of Developing Societies. (2022). *State of rural livelihoods in India*. CSDS.
- Economic Times. (2023, July 18). *Rising input costs and price volatility squeeze small farmers*.
- Food and Agriculture Organization of the United Nations. (2022). *The state of food and agriculture 2022: Leveraging automation in agriculture for transforming agrifood systems*. FAO.
- India Today. (2023, August 5). *Drones take off in Indian agriculture: Promise and challenges*.
- International Energy Agency. (2023). *India energy outlook 2023*. IEA.
- International Labour Organization. (2022). *Global employment trends for agriculture*. ILO.
- Indian Council of Agricultural Research. (2023). *Annual report 2022–23*. ICAR, New Delhi.
- Kumar, R., & Singh, P. (2022). Digital transformation and employment creation in Indian agriculture. *Journal of Rural Development*, 41(3), 357–372.
- Kumar, S., Mehta, R., & Joshi, P. K. (2022). Blockchain and artificial intelligence in agricultural supply chains: Opportunities for India. *Agricultural Economics Research Review*, 35(2), 145–158.



- Mahindra & Mahindra. (2022). *Contract farming and agribusiness integration in India: Industry report*. Mahindra Agri Solutions.
- Ministry of Agriculture & Farmers' Welfare. (2023). *Agricultural statistics at a glance 2022*. Government of India.
- National Institution for Transforming India (NITI Aayog). (2022). *Transforming Indian agriculture through digital technologies*. Government of India.
- NDTV. (2023, June 30). *Farmer suicides in India: Trends and causes*.
- Patil, S., & Sinha, A. (2021). Contract farming, income stability and labour outcomes: Evidence from sugarcane growers in Maharashtra. *Indian Journal of Agricultural Economics*, 76(4), 489–503.
- Press Information Bureau. (2020). *Farm sector reforms and agricultural marketing laws*. Government of India.
- Telecom Regulatory Authority of India. (2022). *The Indian telecom services performance indicators*. TRAI.
- The Hindu. (2023, May 14). *Why young Indians are moving away from farming*.
- The Hindu Business Line. (2023, September 10). *Blockchain traceability and premium pricing in agri exports*.
- United States Department of Agriculture. (2021). *Smart farming and the future of agricultural labour*. USDA.
- World Bank. (2021). *Climate-smart agriculture in South Asia*. World Bank.
- World Bank. (2022). *Gender dimensions of agriculture and rural employment in India*. World Bank.

Volume: 05 Issue No: 12

MARINE PROCESSING BY-PRODUCTS AS BIOFERTILIZERS AND SOIL CONDITIONERS

Article ID: AG-VO5-I12-68**B. Deepika* and P. Ganesan**

Department of Fish Processing Technology, Fisheries College and Research Institute,
Thoothukudi – 628 008, Tamil Nadu, India

*Corresponding Author Email ID: deepikabaskar143@gmail.com

Abstract

The marine processing industry generates large quantities of by-products such as fish heads, bones, skins, viscera, and shrimp shells, which are often treated as waste and disposed of improperly. This not only causes environmental pollution but also leads to the loss of valuable nutrients. Marine processing by-products are rich in organic matter, proteins, minerals, and bioactive compounds that can be effectively utilized as biofertilizers and soil conditioners. Converting these by-products into agricultural inputs provides a sustainable solution that links fisheries with agriculture through a circular economy approach. This popular scientific article discusses the potential, processing methods, benefits, and challenges associated with the use of marine by-products as biofertilizers.

Keywords

Marine by-products, biofertilizers, soil conditioners, fish waste utilization, sustainable agriculture

Introduction

Sustainable agriculture increasingly focuses on improving soil health while reducing dependence on chemical fertilizers. Excessive and prolonged use of synthetic fertilizers has resulted in soil degradation, nutrient imbalance, reduced microbial diversity, and environmental contamination. Simultaneously, the marine processing sector faces serious challenges related to disposal of organic waste generated during fish and shrimp processing.

Marine processing by-products, once considered useless waste, are now recognized as valuable resources. These by-products contain essential nutrients such as nitrogen, phosphorus, calcium, and trace elements, along with organic compounds that enhance soil biological activity. Their utilization as biofertilizers and soil conditioners offers a scientifically sound and environmentally friendly solution that benefits both agriculture and fisheries sectors.

Types of Marine Processing By-Products

During fish and shellfish processing, 40–70% of the raw material may end up as by-products. Common marine by-products include fish heads, frames, bones, skins, scales, viscera, shrimp shells, and crab shells. The quantity and composition of these by-products vary depending on species and processing methods.

Fish bones and frames are rich in calcium and phosphorus, while viscera and trimmings contain proteins and lipids. Shrimp and crab shells are excellent sources of chitin, calcium carbonate, and nitrogen. Due to their high moisture and nutrient content, these by-products are highly perishable and require timely processing to prevent spoilage and odour problems.

Methods of Converting Marine By-Products into Biofertilizers

Fish Silage Production

Fish silage is produced by liquefying fish waste using organic acids or controlled fermentation. This method is simple, low-cost, and suitable for small-scale operations. Fish silage is rich in soluble nutrients and can be applied directly to soil or used as an ingredient in organic fertilizer formulations.

Composting of Marine Waste

Composting involves mixing fish waste with carbon-rich agricultural residues such as straw, sawdust, or coir pith. This stabilizes nutrients, reduces odour, and produces a nutrient-rich compost that improves soil structure and water-holding capacity. Proper aeration and moisture control are essential for effective composting.

Fish Bone and Shell Powder

Fish bones and shellfish shells can be cleaned, dried, and ground into fine powder. These powders serve as slow-release sources of calcium and phosphorus and are particularly useful in acidic soils. They also improve soil pH and root development.

Liquid Organic Fertilizers

Through enzymatic or microbial processing, fish waste can be converted into liquid

organic fertilizers rich in amino acids, micronutrients, and growth-promoting substances. These formulations are suitable for foliar spray and drip irrigation systems.

Impact on Soil Health and Crop Productivity

Marine-based biofertilizers contribute significantly to soil health improvement. Organic matter addition enhances microbial activity, improves nutrient cycling, and increases soil organic carbon. Amino acids and peptides derived from fish waste stimulate plant growth and improve nutrient uptake efficiency.

Studies and field observations have reported improved germination, better vegetative growth, increased flowering, and higher yields in crops treated with fish-based fertilizers. These benefits are especially evident in horticultural crops, vegetables, and pulses, where soil fertility and microbial activity play a critical role.

Environmental and Socio-Economic Significance

Utilization of marine processing by-products reduces environmental pollution caused by dumping and uncontrolled decomposition of waste. It supports circular economy principles by converting waste into wealth. For fish processing units, value addition to by-products creates additional revenue streams.

At the community level, small-scale production of fish silage and compost can be adopted by farmer groups, self-help groups, and rural entrepreneurs. This generates employment, improves farmer income, and strengthens agri-fisheries integration.

Limitations and Way Forward

Despite its potential, large-scale adoption of marine-based biofertilizers faces challenges such as variability in raw material composition, odour management, storage stability, and lack of standardized quality guidelines. Awareness among farmers regarding application methods and dosage is also limited.

Future efforts should focus on developing standard processing protocols, quality standards, and extension programs to promote adoption. Policy support and integration of marine biofertilizers into organic and natural farming systems will further enhance their acceptance and impact.

Conclusion

Marine processing by-products have immense potential as biofertilizers and soil conditioners, offering a sustainable solution to waste management and soil fertility enhancement.

Their utilization reduces environmental pollution, improves soil health, and supports sustainable agricultural production. By adopting scientific processing methods and promoting awareness, marine by-products can play a significant role in building resilient and eco-friendly agri-fisheries systems.

References

- FAO. (2018). *Fishery and Aquaculture By-products: Utilization and Management*. FAO Fisheries Technical Paper.
- Ghaly, A. E., Ramakrishnan, V. V., Brooks, M. S., Budge, S. M., & Dave, D. (2013). Fish processing wastes as a potential source of proteins, amino acids and oils. *American Journal of Applied Sciences*, 10(5), 403–419.
- Rustad, T., Storro, I., & Slizyte, R. (2011). Possibilities for the utilization of marine by-products. *International Journal of Food Science & Technology*, 46, 2001–2014.
- Vidotti, R. M., & Gonçalves, G. S. (2006). Fish silage production and its application in agriculture. *Bioresource Technology*, 97, 189–194.
- Bhaskar, N., & Mahendrakar, N. S. (2008). Protein hydrolysates from fish processing waste and their applications. *Journal of Food Science and Technology*, 45(4), 309–314.

ROLE OF CROP DIVERSITY IN EXPLOITATION OF HYBRID VIGOUR

Article ID: AG-VO5-I12-69***¹S. Saravanan and S. Kaviya Sree**

Rice Research Station, Ambasamudram 627401, Tamil Nadu, India

*Corresponding Author Email ID: saravananspbg@tnau.ac.in

Introduction

Hybrids in crops have been mostly triggered to manipulate the grain yield and yield stability in several crops. Hybrid breeding has been a major stratagem of crop breeders to address the alarming needs of man for food, shelter and clothing. In crops, the genetic yielding ability has been increased greatly contributing increase in total production with minimal dependence on chemical inputs and maximum use of biological power. Hybrid vigour in plants has been exploited on large scale for the past ninety years to trigger out greater performance in grain yield of hybrid cultivars. In crop breeding, genetic diverseness play an important role because hybrid between lines of diverse origin generally display a greater heterosis than those between closely related parents. As such, plant breeders now started exploiting the cause of heterosis based on the extent of genetic diversity available on crop germplasm.

Various statistical methods such as analysis of variance and covariance, statistic, canonical analysis, Mahalanobis and principal component analysis have been employed to assess the genetic diversity wherein the phylogenetic studies were conducted based on the quantitative and qualitative traits of crops. Further, the statistical analysis are mostly based on the quantitative traits which are highly influenced by environmental effects and require statistical procedures.

Wider genetic diversity and the greater hybrid vigour

Normally, it has been stated that the genetic diversity play a major role in the expression of heterosis. With the start, as early as 1963, Hayes reported the usefulness of utilizing inbred lines obtained from diverse sources in the expression of heterosis. He utilized three dent and four

flint sources for the introduction of inbred lines and made crosses between the lines obtained from same group and also between different groups. The heterotic expression was larger when the crosses were made between various groups than those between the lines obtained from the same source from both dent as well as the flint populations.

Hassanin *et al.*, (2025) studied the genetic potential of the inbred lines, laying a strong foundation for developing resilient, high-yielding maize hybrids for arid and semi-arid environments. Integrating phenotypic and molecular data provides valuable insights for selecting suitable inbred lines in hybrid maize breeding.

Shull (1948) observed that the physiological vigour of an organism is manifested in its rapid growth, height and general robustness is positively correlated with the degree of dissimilarities in the gametes by whose union the organism was formed signifying the impact of heterosis. The more numerous the differences between the uniting gametes, the greater on the whole would be the amount of stimulation. Shull's observation clearly showed that the idea of genetic diversity as a mechanism leading to expression of vigour of the hybrids was inherent in his preparation for the term heterosis.

The maize improvement program at IITA, analyzed the pedigree information of 623 subtropical maize inbred lines generated at the IITA maize breeding program to identify the key founder inbred lines. Around 5032 SNP markers were employed to assess the genetic similarities of the founder inbred lines with their progenies subsequently developed for specific target traits. Inbred line, TZMi501 belonging to a flint heterotic group (HGA), and TZMi407-S and TZMi214, representing the dent heterotic group (HGB), were identified as the most useful founder inbred lines. The 623 inbred lines were consistently separated into four clusters based on Ward's hierarchical clustering, structure, and principal component analyses, with the 20 founder inbred lines spread into all clusters. The founder inbred lines were more genetically related to the productive inbred lines but showed genetic divergence from the provitamin A enriched inbred lines (Gedil *et al.*, 2025).

Sang Zhi-qin *et al.*, (2025) evaluated 737 hybrids derived from 41 maize inbreds were evaluated over two years, with the aim of assessing the genetic diversity and their performance between heterotic groups under drought-stressed (DS) and well-watered (WW) treatments. A total of 38 737 SNPs were employed to assess the genetic diversity. The genetic distance (GD) between the parents ranged from 0.05 to 0.74, and the 41 inbreds were classified into five

heterotic groups. The results indicated that heterosis is due to the combined accumulation of superior genes/alleles in parents and the optimal genetic distance between parents, and that yield heterosis under DS treatment was mainly determined by the non-additive effects.

In faba bean, Upadhyay and Pandey (2025) demonstrated substantial genetic divergence among the 47 faba bean genotypes, are grouped into five clusters through cluster analysis. Cluster II consisted 19 genotypes, making the largest cluster. The maximum intra cluster distance was observed for cluster IV, followed by cluster III, whereas, minimum intra cluster distance was observed for cluster V and the maximum inter-cluster distance was observed between cluster I and cluster IV, whereas, minimum inter cluster distance was recorded between cluster I and cluster V. Genotypes from cluster IV indicated highest mean value for marketable pod yield per plant, therefore, genotypes in this cluster can be selected for hybridization to develop high marketable pod yielding variety in faba bean.

Shailaja *et al.*, (2025) grouped twenty six wheat genotypes into six distinct clusters. Cluster V was the largest with eight genotypes, followed by Cluster I (six genotypes), Cluster IV (five genotypes), Cluster VI (three genotypes), while Clusters II and III contained two genotypes each. The highest intra-cluster distance was observed in Cluster IV, followed by Cluster III, whereas the greatest inter-cluster distance was recorded between Clusters IV and VI. These results suggest that selecting parents from clusters with higher inter-cluster distances would increase the probability of generating superior segregants, thereby enhancing the chances of developing improved cultivars. Trait contribution analysis revealed that 1000 grains weight (g), grain yield/plot (kg), and biological yield/plot (kg) were the major contributors to overall genetic divergence. The report had shown the importance of these traits in driving variability and suggested their potential as key selection criteria in wheat improvement programs.

Bhor et al (2024) assessed the genetic diversity among 50 chickpea genotypes using Mahalanobis D2 statistics to identify potential parents for breeding programmes during rabi 2022-23 at Zonal Agricultural Research Station, Ganeshkhind, Pune, Maharashtra. The results hinted that the Clusters IV and X having genotypes Phule G-1424-4-2 and Vijay exhibited larger genetic variation. Based on *per se* performance and intra- and inter-cluster distance genotypes Jaki-9218, Phule Vikram, Vishal, TRCH-4, Local Gawadevadi, Local Awasari-3, Phule G-1424-4-2, Phule G-14481, C-2266, C-2265, Phule G-1403-18-14, Vijay and Digvijay were found promising for cultivation and could be used as potential parents in future crop improvement

programmes.

Therefore, it could be construed that many more scientists working in various crops have noted direct relationship between parental divergence and extent of heterosis in the hybrids upto a certain extent and there after a negative relationship was found to occur indicating the existence of an optimal level of parental divergence for realising heterotic hybrids.

Measurement of Genetic divergence

i. Morphological traits and pedigree records

D² statistics referred to one of the potent techniques of assessing genetic divergence using phenotypic traits and therefore extensively used in plant breeding. Selected genotypes are evaluated in replicated trials and data were recorded on various quantitative or qualitative traits. Computed D² values are used to group the genotypes into different clusters on a dendrogram. Genotypes falling in the same cluster are likely to be more closely related than genotypes of other clusters.

Although the phenotypic traits has proved to be useful for classifying different races of genotypes and population (Goodman and Brown, 1988) it may not be appropriate for elite breeding germplasm (Smith and Smith, 1989). Further, morphological characters can be effected by environmental condition. (Goodman and Paterniani, 1969).

Pedigree relationship often considered as a standard protocol to evaluate the effectiveness of morphological and biochemical markers in determining relationships among lines and predicating heterosis. Nevertheless, estimates of distance measures based on pedigree have several shortcomings. Some of the assumptions made in the calculation of pedigree relatedness may not be valid particularly the assumptions of equal contribution from parents and lack of selection in derivation of new lines (Smith and Smith, 1989). Also, pedigree relationship may sometimes be unavailable and erroneous (Smith *et al.*, 1990).

ii. Protein and Isozyme markers

Specific genes produce specific proteins which can be separated by electrophoresis to determine the presence or absence of specific allele that is coding for the protein. Isozymes are enzymes that exist with different structures but with same enzymatic activity. These markers have the following limitations: Low level of polymorphism, failure to detect polymorphism due to single base substitutions. Expression of isozyme markers in ontogeny and environment dependent.

iii. Markers at DNA level

Wide range of restriction enzymes has opened the door to carry out the genome analysis with great precision using cloned unique sequences as probes against gels of restricted nuclear DNA – the segregation of innumerable loci can be monitored and mapped. The markers at DNA level can be broadly classified into two categories.

- a) Hybridization based markers
- b) PCR based markers

The following are the list of molecular markers available at DNA level for genetic diversity analysis.

1. Restriction Fragment Length Polymorphism
2. Randomly Amplified Polymorphic DNA
3. Sequence Tagged Sites
4. Sequence Characterized Amplified Regions
5. Variable Number Tandem Repeats
6. Amplified Fragment Length Polymorphism

Genetic interpretation of molecular marker with genetic distances and hybrid performance

The evolution of molecular DNA markers has provided tools to assess the genetic diversity among inbred lines and to assign them to different heterotic groups. Many studies have reported the estimates of correlation between marker based genetic distances (GD) and hybrid performance in different crops. Three types of crosses could be distinguished for computing correlations of genetic distance and performance of hybrids. a. Crosses between related lines, b. Crosses between unrelated lines from the same germplasm and c. Crosses between (unrelated) lines from different heterotic groups.

Conclusion

Heterotic pools are made as divergent as possible because the heterosis depends on the differences in allele frequency between two populations. Genes concerned to contrasting traits in two heterotic pools should be considered. For example, the female parent should possess high yield potential and other desired agronomic traits whereas the pollen parent should provide enough pollen at the level of fertilization or above and should have good pollen spread. The utility of exotic germplasm to broaden the genetic base and as a source of new genes particularly for disease and pest resistance is well recognized. The choice should be based on geographic

origin, pedigree and heterotic patterns, besides performance *per se* and in crosses with adapted germplasm. Besides the genetic diversity showing impact on heterosis, germplasm serves also as a reservoir of male sterility genes particularly wild forms and wild relatives.

References

- Bhor, V.B., Lad, D.B., Bhagat, A.A. and Shitol, L.S. 2025. Genetic diversity studies in chickpea (*Cicer arietinum* L.) genotypes under late sown condition. *International Journal of Farm Sciences* 15(1): 57-63, 2025; doi: 10.5958/2250-0499.2025.00007.6
- Gedil, M., Maazou, A.R.S., Zebire, D.A. *et al.* Genetic structure analysis and identifying key founder inbred lines in diverse elite sub-tropical maize inbred lines. *Sci Rep* **13**, 11695 (2023). <https://doi.org/10.1038/s41598-023-38980-3>
- Goodman, M. M. and E. Paternian.: 1969. The races of Maize. III. Choices of appropriate characters for racial classification. *Econ. Bot.*, 23: 265 – 271.
- Goodman, M. M. and W. L. Brown. 1988. Races in Maize. In: G. F. Sprague and J.W. Dudley (ed). *Corn and corn experiment 3rd ed.* Agron. Monogr. 18. ASA, Madison, WI.
- Hassanin AA, Jalal AS, Mahdy EM, Mandour H, Mansour E, Kamara MM, Alshaharni MO, Fayad E, Alqurashi M, Aljabri M, Fallatah TA, Abd El-Moneim D, Eldomiaty AS. 2025. Unravelling agronomic performance and genetic diversity of newly developed maize inbred lines for arid conditions. *PeerJ* 13:e19598
- Hayes, H. K. 1965. A Professor's story of hybrid corn. Burgess Publ. Co. Minneapolis, 23 pp.
- Shull, G. H. 1948. What is heterosis? *Genetics*, 33: 439 – 446.
- Smith, J. S. C. and O. S. Smith. 1989. The description and assessment of distances inbred lines of maize II. The ability of morphological, biochemical and distinctness between inbred lines. *Maydica*, 34: 151 – 161.
- Smith, O. S., J.S.C. Smith, S. L. Bowen, R. A. Tenberg, and S. J. Wall. 1990. Similarities among a group of elite maize inbreds as measured by pedigree, F₁ grain yield, heterosis and RFLPs. *Theor. Appl. Genet.*, 80: 833 – 840.
- Upadhyay, D and Pandey, K.K. (2025). Studies on Genetic Divergence in Faba Bean (*Vicia faba* L.). *Indian Journal Of Agricultural Research*. 59. 1046-1050. 10.18805/IJAR.A-6268.

SILAGE AND THEIR BENEFITS

Article ID: AG-VO5-I12-70**Rajan L Fradlin Singh¹ and Monisha. R^{2*}**

1.Assistant Professor, Department of Agricultural Microbiology, Krishna College of Agriculture and Technology, Madurai

2.Associate Professor, Department of Agricultural Engineering, Park college of Engineering and Technology, Coimbatore

*Corresponding Author Email ID: monisharajkumar95@gmail.com

Introduction

Forage made by fermenting plant materials in anaerobic circumstances until it becomes acidified is known as silage. Although it is mostly used for cattle, it is also fed to domestic animals including sheep, goats, and pigs. Silage can be produced from a wide range of plants. Sorghum, alfalfa, corn, cereals, and other legumes are a few examples. Silage is made from the entire corn plant, including the leaves and stems, in contrast to corn kernels, which are provided whole or in flour and mixes. For domestic animals, silage is regarded as a nutritious roughage that is especially appealing because of the scent that is created during fermentation. The plant materials are preserved as silage or hay during scarcity period for sustained animal growth and milk production throughout the year. Hay making is mostly dependent on weather condition, due to lack of drying facilities in developing countries. Silage could be used at any time when required, particularly during periods of drought (Koon,1993). Different grasses and a variety of other crops, including grains such as alfalfa, Sudan grass, millets, and sorghums, as well as cereal crops such as barley, oats, rye, triticale, and wheat, are used to make silage for cattle with varying nutritional benefits. When fed to animals, these silages contain variable amounts of nutrients. (Show,2002).



Environmental requirements

Environmental factors affect yield, growing season length, and final product quality. It is possible to cultivate corn both with and without irrigation. In most areas, farmers decide to irrigate in order to produce silage and attain large yields. Lastly, temperature is a significant environmental component; 35 °C (95 °F) is excellent for maize growth.

Fertilization

A silage crop removes more nutrients from the field because the entire plant is taken, and agricultural leftovers such as stalks do not return to the soil. Nitrogen requirements for silage corn cultivation range from 200 to 300 kg per hectare (178 to 268 pounds per acre). This number can vary according on the plot's cultivation intensity (sowing density), previous cultivation, and fertility. Furthermore, the crop requires 30-40 kilograms of phosphorus (P) per hectare (27-36 pounds per acre) and up to 160 kg of potassium (K) per hectare (143 pounds per acre). In any case, over-fertilization should be avoided as it can lead to excess nitrate and potassium concentrations in the silage, leading to nutritional disorders in dairy cows during the dry season.

Cutting stage

Cutting the stems is critical since it influences both the amount of production (yield) and the product's digestibility (quality and quantity). According to studies, late cuttings produce fewer non structural carbs and more fiber. The optimum Dry Matter (DM) content is from 33-36%. When estimating maturity from grain observations, some recommend harvesting when the milk line is between $\frac{1}{3}$ and $\frac{1}{2}$, while others between $\frac{1}{2}$ and $\frac{2}{3}$. The milk line is the "dividing line" between the seed's starchy outer layer and the softer milky center.

Forage harvesting

Harvesting the stems involves cutting 10 cm from the ground. Increasing the cutting height only marginally improves the quality of the silage while reducing its quantity. The majority of farmers rely only on machines for harvesting. Harvesting is done by hand and only with tiny instruments, primarily for shredding, on small-scale farms with more personnel available.

Silage process

The shredded corn enters the silo, which will be compacted and covered to begin the silage process. Silage can be produced in vast piles where farm tractors continually trample the feed, in large tonne capacity bags, plastic containers, or even in little sacks. In all circumstances, ensilage

is designed to create anaerobic conditions. After closure, the aerobic bacteria begin to consume oxygen, generating carbon dioxide and heat. With the lack of oxygen, anaerobic bacteria of the genus *Lactobacillus* begin to proliferate, producing lactic acid, which functions as a preservative due to the pH drop and provides the product a nice flavour and taste. Producers frequently inoculate their products with formulations that protect them from fungal action and Mold growth. Inoculants typically comprise strains of the species *L. buchneri*, *L. casei*, *L. plantarum*, *L. lactis*, *Enterococcus sp.*, and *Pediococcus sp.*. Aside from the inoculants, molasses (sugars), urea or ammonia (nitrogenous substances in low protein situations), and calcium can be added. The finished product will be ready within 4-6 weeks. In average, silage comprises 40-60% water (which reduces with cutting delays), fibrous particles neutral detergent fiber (NDF) 41-52% in Dry Matter, and the most indigestible acid detergent fiber (ADF) 24-32%, as well as proteins 6-8%. These fibers shrink as the seed grows. The pH ranges from 3.7 to 4.1.



References

- Koon L.L. Production of Silawrap Silage Form Fodder Grass Species for Dry Season Feeding. In: Strategies for suitable forage-based livestock production in S.E. Asia. Proc. 3rd Meet. Region. Working Grp. On Grazing and Feed Resources for S.E. Asia. 1993, 99-101.
- Show S. Ensiling of Tropical Forages with Particular Reference to South East Asian Systems. In Paper presented at the XIIIth International Silage Conference. 2002, 11.

USE OF ARTIFICIAL INTELLIGENCE IN AGRICULTURE: TECHNOLOGIES, APPLICATIONS, AND FUTURE DIRECTIONS

Article ID: AG-VO5-I12-71***Dr. Ramesh N. Dhawale¹ and Dr. Achut A. Bharose²**

¹ Assistant Professor, V. D. College of Agril. Biotechnology, Latur, Vasantao Naik Marathwada Agricultural University, Parbhani, Maharashtra, India

² Associate Dean and Principal, V. D. College of Agril. Biotechnology, Latur, Vasantao Naik Marathwada Agricultural University, Parbhani, Maharashtra, India

*Corresponding Author Email ID: ndramesh11@gmail.com

Abstract

Agriculture is undergoing a fundamental transformation driven by rapid advancements in Artificial Intelligence (AI), robotics, automation, remote sensing, and data analytics. AI enables farmers, agronomists, and agricultural enterprises to optimize crop yields, reduce resource consumption, detect diseases early, and improve climate resilience. This technical article presents a comprehensive analysis of AI applications in agriculture, including machine learning (ML), computer vision, robotics, autonomous systems, geospatial intelligence, and predictive analytics. Challenges, limitations, case studies, and future research opportunities are also discussed.

Introduction

Agriculture is the backbone of the global economy, supporting food security, employment, and economic development. According to FAO projections, the world must increase food production by approximately 70% by 2050 to feed a growing population—a goal complicated by shrinking arable land, climate change, labor shortages, and unpredictable weather patterns. Traditional agricultural practices alone cannot meet these demands.

Artificial Intelligence offers innovative solutions. By integrating sensors, drones, big data, and machine learning models, farmers can transition from labor-intensive, intuition-based decision-making to data-driven precision agriculture. AI allows continuous monitoring of soil

health, plant growth, pest populations, and environmental conditions with unprecedented accuracy.

This article provides a seven-page technical review of how AI is transforming modern agriculture, organized into key thematic areas including technologies, applications, challenges, case studies, and future directions.

Core AI Technologies Used in Agriculture

AI in agriculture relies on a combination of subfields and complementary technologies:

1 Machine Learning (ML)

ML algorithms extract patterns from agricultural data to support tasks such as:

- Crop yield prediction
- Disease classification
- Soil fertility estimation
- Weather forecasting
- Farm-cost optimization

Common models include:

- Random Forests
- Gradient Boosting Machines (GBM)



[Chunxia Jiang, et al., 2025]

- Support Vector Machines (SVM)
- Convolutional Neural Networks (CNNs)
- Recurrent Neural Networks (RNNs) and LSTMs for time-series data

Computer Vision

Computer vision enables identification and analysis of visual patterns in crops, fruits, soil, and livestock. **Uses include:**

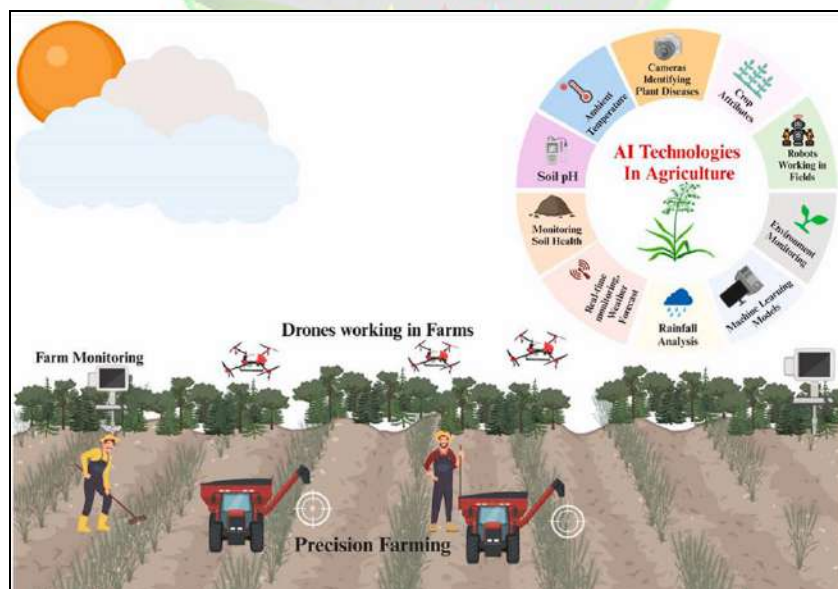
- Leaf-based disease detection
- Weed identification
- Fruit counting and ripeness assessment
- Livestock monitoring (posture, distress detection)

Vision models often employ CNN architectures such as ResNet, EfficientNet, YOLO, and Mask R-CNN.

Robotics and Automation

AI-driven agricultural robots perform repetitive or labor-intensive tasks. Examples:

- Autonomous tractors
- Weeding robots using mechanical arms or laser precision
- Robotic fruit pickers



[Nazish Aijaz, et al., 2025]

- Drone-based crop monitoring
- Automated irrigation systems

These robots rely on sensor fusion (LiDAR, GPS, radar) and reinforcement learning algorithms

Internet of Things (IoT) and Sensor Networks

IoT devices collect continuous data about:

- Soil moisture
- Nutrient concentration
- Temperature, humidity
- Livestock movement
- pH and EC levels

AI transforms sensor data into actionable insights through predictive models.

Geographic Information Systems (GIS) and Remote Sensing

Satellite imagery and drone data combined with AI support:

- Land use classification
- Crop health monitoring (NDVI, EVI indices)
- Precision fertilization maps
- Pest/disease hotspot identification

Applications of AI in Agriculture

AI enables a wide range of applications, from early detection systems to autonomous operations.

This section discusses key use cases in detail.

1.1 Precision Agriculture

Precision agriculture tailors farm management to spatial and temporal variability.

1. Variable Rate Technology (VRT)

AI determines optimal application rates for:

- Fertilizers
- Pesticides
- Irrigation
- Seeds

Economic benefits include reduced input waste and improved productivity.

2. Soil Health Mapping

ML models analyze soil properties to produce high-resolution nutrient maps, informing fertilizer recommendations.

1.2 Crop Disease and Pest Detection

Crop diseases cause up to 40% annual yield losses globally. AI-based early warning systems use:

1. Image-Based Disease Diagnostics

Farmers capture leaf images using smartphones; ML models classify diseases such as:

- Late blight in potatoes
- Maize leaf rust
- Rice blast
- Tomato yellow leaf curl virus

Accuracy can exceed 95% with high-quality datasets.

2. Pest Population Forecasting

Time-series models predict outbreaks using weather and historical pest data. This supports targeted pesticide spraying.

1.3 AI in Irrigation and Water Resource Management

1. Smart Irrigation Systems

Sensors + AI regulate water flow based on:

- Soil moisture thresholds
- Crop evapotranspiration (ET) models
- Real-time weather data

Reduces water consumption by 30–50%.

2. Drought Prediction

AI analyzes hydrological data to forecast drought periods, helping farmers plan irrigation cycles or choose drought-resistant crops.

1.4 Autonomous Vehicles and Agricultural Robotics

1. Self-driving Tractors

These tractors use:

- GPS-guided autopilot
- Computer vision for obstacle avoidance
- AI to optimize path planning

2. Automated Harvesting Robots

Robots detect, localize, and pick fruits or vegetables using:

- Vision-based recognition
- Robotic arms with motion planning
- Reinforcement learning for picking strategy optimization

Examples include strawberry and apple harvesting robots.

3. Weeding Robots

These robots identify and remove weeds using:

- Mechanical extraction
- Targeted herbicide micro-dosing
- Laser precision

1.5 Supply Chain Optimization

AI improves efficiency across the agricultural value chain:

1. Post-harvest Grading

AI-based quality assessment tools classify produce based on:

- Size
- Color
- Defects
- Texture

2. Logistics Optimization

ML models reduce transportation cost and post-harvest losses by predicting:

- Optimal storage conditions
- Dynamic routing for food distribution
- Inventory demand forecasting

1.6 Livestock Monitoring

AI in animal husbandry includes:

1. Health Monitoring

Wearable sensors track:

- Body temperature
- Feeding patterns
- Stress levels

- Mobility

Algorithms detect early signs of disease such as mastitis in dairy cattle.

2. Precision Feeding

ML models calculate optimal feed composition for each animal, reducing cost and improving growth rate.

Case Studies

1. India's Precision Agriculture Adoption

AI startups in India like CropIn, Fasal, and KisanAI use satellite imagery and ML models to predict yields and provide advisories to millions of farmers. This has reduced input cost by 15–20% and increased yields by up to 30%.

2. John Deere Autonomous Tractor

John Deere's fully autonomous tractor integrates computer vision, GPS navigation, and sensor fusion to conduct plowing and tilling without human intervention.

3. AI-Based Disease Detection in Africa

AI-powered smartphone apps help smallholder farmers detect diseases in cassava, maize, and banana crops, reducing losses that typically reach 20–30% annually.

Benefits of AI in Agriculture

1. Increased Productivity

AI improves yields through optimal planting schedules, targeted inputs, and early threat detection.

2. Reduced Costs

Precision resource management reduces:

- Fertilizer by 10–25%
- Water usage by 30–50%
- Pesticide application by 20–40%

3. Enhanced Sustainability

AI supports conservation agriculture by minimizing chemical overuse and improving soil health.

4. Improved Decision-Making

AI systems provide data-driven recommendations rather than intuition-based decisions.

Challenges and Limitations

Despite significant potential, several challenges remain.

1. Data Scarcity and Quality Issues

Agricultural data is often:

- Unstructured
- Noisy
- Geographically variable

This affects ML model performance.

2. High Upfront Costs

Adoption is difficult for smallholders due to cost of:

- Sensors
- Robots
- Drones
- IoT infrastructure

3. Digital Literacy Gap

Limited technical knowledge restricts AI adoption in rural regions.

4. Ethical and Privacy Concerns

Farm data ownership and usage rights require clear policies and regulations.

5. Infrastructure Constraints

Rural areas often lack:

- Stable internet connectivity
- Electricity
- Cloud computing access

Future Directions

1. Integration of Generative AI

Generative AI can:

- Create synthetic training data
- Simulate crop growth under different climate scenarios
- Design optimized farm plans

2. Fully Autonomous Farms

Future farms will operate with minimal human intervention:

- AI-driven machinery
- Real-time decision systems

- Automated irrigation, fertilization, and harvesting

3. AI + Blockchain for Traceability

Blockchain ensures transparent food supply chains, while AI detects anomalies.

4. AI for Climate-Resilient Agriculture

Models will help farmers adapt to extreme weather conditions through:

- Real-time climate forecasting
- Crop-climate suitability predictions
- Adaptive planting strategies

5. Multi-Agent Systems

Collaborative AI agents representing soil, crop, and climate models will coordinate to optimize entire ecosystems.

Conclusion

AI is reshaping modern agriculture by enabling precise, automated, and intelligent farming practices. It offers transformative potential across the entire agricultural lifecycle—from planting and monitoring to harvesting and distribution. Despite the challenges of cost, data quality, and digital literacy, advancements in affordable sensors, open-source AI models, and rural connectivity are accelerating adoption worldwide.

As global food demand continues to rise, AI will play a crucial role in building a resilient, productive, and sustainable agricultural future. Continued research, policy support, and technological innovation will be essential to realizing the full potential of AI in enabling the next agricultural revolution.

References

1. <https://doi.org/10.1016/j.jafr.2025.101762>
2. <https://doi.org/10.3390/pr13051402>

Volume: 05 Issue No: 12

ENVIRONMENT PROTECTION THROUGH GREEN AND CLEAN AGRI-UNIVERSITY CAMPUS –A SUCCESS STORY

Article ID: AG-VO5-I12-72***J S Sandhu¹ and S P Singh²**

¹Former Vice Chancellor, SKN Agriculture University, Jobner, Jaipur
Professor Chair, Guru Gobind Singh Chair, Patanjali University, Uttra Khand, and
DDG (CS), ICAR And Agriculture Commissioner, GoI, New Delhi,

²Professor (Horticulture), SKN Agriculture University, Jobner, Jaipur, India

*Corresponding Author Email ID: js_sandhuin@yahoo.com

Introduction

Globally environment protection is a key issue of discussion and that reason every year on 5th June Environment Day is observed to create awareness to save and safe gaurd the enviornment. The collective efforts are needed save environment to pass own to coming generations to live happily. The environment is polluted due to green houses emissions, it may be from industry & Construction, vehicular traffic, agriculture, fertilizers, electricity generation and various other human induced activities. These activites induce climate change which deteriorate the enviornment. The protection, adaptation and mitigation are three main approaches are widely followed to safe guard the environment.



SKN Agriculture University

We at SKN Agriculture University made efforts to protection and adaptation approaches of environment were followed. Our endeavour to achieve the target through developing Green and clean campus and conserving of natural resources. The university campus spread over 186 hectare land and out campus possess over 1000 hectare land. I joined as Vice Chancellor in 2019 and surprised to see there a few old trees mainly khjrdi and small orchard of ber and citrus. Overall look was like a desert. It is quite relevant to mention here the agriculture college was established in July 1947 and this college was allivated as an agriculture university in 2013. As soon I start working to collected base data of trees on campus and it is reported about 2000 plants are there.



SKN Agriculture University, Jobner

Rain harvesting structures

What I understood that main reason for low plantation was acute shortage of water and occasionally demand was met through purchase water tankers. Although a few rain harvesting structures was already there. My first priority was to improve academic, research and extension quality of university. Besides, I decided to improve rain water harvesting while connecting roof top for rain harvesting and other measures like rain water flow to develop slop for proper runway to flow down rain water to the ponds those was already exist. Although, annual rainfall of campus is just 400 -500 mm and in first monsoon, we were successfully harvested sufficient rain water and that gives us confidence, more rain water harvesting is possible.

We made efforts to develop more rain harvesting structures at different points on campus and out stations. In two years span we developed rain water harvesting capacity over 29 crore liter capcity including 19 crore liter at main campus and old ponds also improved to hold more

water and interconnected with each ponds with others. Secondly, a drinking water pipeline is passing near VC residence to maintain water supply to rural area near by villages. Infront of VC house, a hydrant was stall to remove air from pipeline and occasionally thousands liters of water flow out and go waste on road to tap this water small chabutra was constructed and connected inside in small ponds. This way, we have enough water to meet water requirement of VC residence.



Tree Plantation

The water collected in all ponds was good have enough to meet the domestic demand and farm experiments The spare water also provided for university farm to produce quality seeds of different crops to enhance the income of university. The sensor based drip/spinklar system for irrigation was used. The With initial success rainwater harvesting let take us task of tree plantation at all the university campuses in jurisdiction.



Over two and half year, we planted over 38000 plants and survial rate was over 80%. Today, most of plant attained height upto 15-20 feet. The mostly plants of economic use like

neem, shehmum, Jamun, Cranch, Sagwan, Rohirya, Ardoo (fodder tree) Parijat, Kadam, Kacnar, Ker etc. AS part of tree plantation, The biodiversity Park was developed inside VC residence in 2020 and inaugurated by Padam Vibhushan Dr R S Paroda and subsequently, honourable Governor of Rajasthan and Chief Minister of Rajasthan Government, planted tree on different occasions.



Tree Plants

The plants from temperate region like Badam, Peach, Pears and Plum, Apple, Gauwa, Kinoo, Mosumi, Niboo, Sagwan, Chandan: from sub-tropical region Mango, Awala, Jamun, Lasuda, Bail, Castared apple, Morriga, Jack fruit, Shtoot etc from arid region ker, karoda, Date Plam, Ber, Lasuda, Rordiya, Ardoo, imali ,varous types of plam trees: from Tropical region grapes and from costal area naarial trees like this over 150 plant species including ornamental plants were part of biodiversity park.



Sagwan Plant

This sarve not only conserve the plant biodiversity, it is also important as instructional cente for B.SC. PG students, and staff and adepation studies if plant species from out of region. Third important activity under taken was installation solar penals at roof tops, waste residue management, Sewerage treatment of grey water, Plastic free, new lawn, e-rickshas and fixing+ Napkin Shedders in girls hostels as have clean environment. All this happen with the collective and active supports of Deans, Directors, university faculty including students and Dr S P Singh, Professor Horticulture and Incharge Land Scaping. His contribution in developing green clean campus was enormous which is duly acknowledged. The covid 19 given me enough time to nurture plants and it success story of green , clean and natural resources conservation for the protection of environment.



Volume: 05 Issue No: 12

MICROCOSM STUDY ON SEDIMENT–WATER INTERACTIONS AND THEIR INFLUENCE ON PHYSICOCHEMICAL DYNAMICS IN AQUATIC ENVIRONMENTS

Article ID: AG-VO5-I12-73***A.Kaviya Niranjana, S. Aruna and S. Kumaaraguru**

TNJFU- Dr. MGR. Fisheries College and Research Institute, T.H. High Road, Ponneri
Taluk, Thiruvallur District, Tamil Nadu 601 204. India

*Corresponding Author Email ID: kavivaniranjana015@gmail.com

Abstract

Sediment-water interactions play a crucial role in regulating nutrient cycling, redox transformations, and the behavior of contaminants in aquatic environments. Microcosm experiments provide a controlled setting to study these interactions by mimicking actual conditions of sediment and water. This article examines how important physicochemical factors—such as pH, temperature, dissolved oxygen (DO), electrical conductivity (EC), alkalinity, organic matter, cation exchange capacity (CEC), and nutrient levels—affect sediment-water exchanges. The paper also focuses on the role of microbial processes, redox gradients, and implications for management. The results emphasize that even minor variations in environmental conditions can significantly impact nutrient fluxes, internal loading, and the overall health of aquatic ecosystems.

Introduction

The sediment–water interface (SWI) represents a critical boundary in aquatic ecosystems where the exchange of solutes, gases, and nutrients controls biogeochemical cycling (Jørgensen & Revsbech, 2021). In reservoirs and lakes, this interface governs internal nutrient loading, influencing eutrophication, productivity, and water quality (Andersen et al., 2021). Microcosm systems are miniature experimental setups that replicate natural conditions, allowing scientists to manipulate environmental variables such as redox state, temperature, and organic matter input. They are essential in understanding mechanisms behind nutrient regeneration, contaminant mobility, and ecological balance (Zhou et al., 2018; Gao et al., 2023).

Sediment–Water Interface Dynamics

At the SWI, nutrient fluxes occur primarily through diffusion, microbial activity, and chemical adsorption–desorption reactions. Under oxic conditions, sediments act as nutrient sinks, binding phosphate to iron and manganese oxides. When anoxic conditions develop, these oxides are reduced, releasing bound phosphate and ammonium into the overlying water (Mortimer et al., 2020).

The diffusive boundary layer thickness, temperature, and sediment composition dictate the rate of exchange. Microcosm observations have revealed that reduced oxygen levels enhance the mobilization of NH_4^+ , PO_4^{3-} , and dissolved organic carbon, leading to increased nutrient flux and internal loading (Zhang et al., 2019).

Influence of Water Quality Parameters

pH and Alkalinity

pH governs the solubility and chemical speciation of ions at the SWI. High pH favors phosphate and metal hydroxide precipitation, while acidic conditions increase desorption and mobilization of metals and nutrients (Mortimer et al., 2020). Alkalinity provides buffering capacity, protecting against acidification caused by microbial decomposition or CO_2 accumulation. Stable alkalinity ensures redox balance and mitigates the effects of acid-base fluctuations (Wetzel, 2001).

Temperature and Dissolved Oxygen (DO)

Temperature regulates microbial metabolism and enzymatic reaction rates. Warmer conditions accelerate organic matter degradation and enhance nutrient mineralization (Zhang et al., 2019). Dissolved oxygen is a critical determinant of redox potential. Oxygenated sediments support nitrification and phosphate adsorption, whereas anoxia triggers denitrification and phosphate release, thereby driving eutrophication (Andersen et al., 2021).

Electrical Conductivity and Ionic Strength

Electrical conductivity reflects the concentration of dissolved ions. In microcosm studies, increased EC indicates higher ionic mobility due to desorption or dissolution of sediment minerals. Fluctuations in EC can also signal saline intrusion or anthropogenic influence (Reddy & D'Angelo, 1997).

Influence of Sediment Characteristics

Organic Matter and Cation Exchange Capacity (CEC)

Organic matter is a key driver of microbial respiration and nutrient cycling. Its decomposition reduces redox potential and enhances nutrient release. The CEC of sediments determines their ability to adsorb or exchange cations such as Ca^{2+} , Mg^{2+} , and K^{+} . Sediments with high CEC possess greater buffering and nutrient retention capabilities (Mortimer et al., 2020; Li et al., 2022).

Sediment Texture and Nutrient Content

Sediment texture, defined by the proportion of sand, silt, and clay, influences porosity and diffusion rates. Fine-grained sediments rich in clay and organic matter retain nutrients longer but may also promote localized anoxia. Total nitrogen (TN) and total phosphorus (TP) contents are useful indicators of the long-term nutrient storage potential of sediments (Wetzel, 2001; Zhou et al., 2018).

Microbial Mediation in Sediment–Water Interactions

Microorganisms play a central role in regulating nutrient transformations and redox reactions. Aerobic microbes promote nitrification and phosphate immobilization, whereas anaerobic microbes facilitate processes like sulfate reduction, methanogenesis, and denitrification.

Recent studies using molecular tools have shown that microbial community structure shifts in response to DO, pH, and organic loading (Liu et al., 2021). Microcosm-based metagenomic analyses reveal that microbial assemblages adapt rapidly to redox changes, influencing nutrient regeneration and contaminant degradation.

Anthropogenic and Environmental Influences

Reservoirs and lakes are subject to anthropogenic pressures such as agricultural runoff, sewage discharge, and sediment dredging. These inputs alter sediment chemistry, increase organic load, and accelerate eutrophication (Wang et al., 2022). Climate change adds further complexity—warming enhances stratification and oxygen depletion, while increased rainfall promotes sediment resuspension and nutrient release. Microcosm experiments have been instrumental in quantifying such changes under controlled temperature and hydrological regimes (Zhou et al., 2018).

Management and Restoration Perspectives

Understanding sediment–water interactions through microcosm studies aids in developing effective management interventions.

- Sediment aeration and capping can prevent phosphate release under anoxic conditions.
- Biomanipulation and microbial augmentation may enhance nutrient immobilization.
- Reducing external nutrient inputs from catchments remains a long-term strategy for preventing eutrophication.

Integrating microcosm data with field-scale monitoring helps refine predictive models for nutrient fluxes, thereby supporting sustainable management of reservoirs like Poondi and Krishnagiri in Tamil Nadu.

Conclusion

Microcosm studies reveal the interdependent nature of physicochemical parameters at the sediment–water interface. Factors such as pH, temperature, DO, EC, and sediment composition collectively influence nutrient mobility and water quality. Microbial mediation further enhances the complexity of these processes. By replicating natural sediment–water systems, microcosm experiments offer valuable insights for predicting ecological responses to environmental change and form the scientific foundation for effective aquatic ecosystem management.

References

- Andersen, F. Ø., Jensen, H. S., & Nielsen, O. I. (2021). Nutrient fluxes across the sediment–water interface in lakes and reservoirs. *Hydrobiologia*, 848(7), 1607–1621.
- Gao, L., Liu, C., & Tang, Y. (2023). Experimental approaches to sediment–water nutrient exchanges under changing redox states. *Environmental Science and Pollution Research*, 30(11), 18427–18438.
- Jørgensen, B. B., & Revsbech, N. P. (2021). Diffusive boundary layers and the sediment–water interface. *Nature Reviews Earth & Environment*, 2, 402–417.
- Li, X., Zhao, J., & Feng, S. (2022). Effects of sediment characteristics on nutrient release in eutrophic reservoirs. *Ecological Indicators*, 139, 108923.
- Liu, Y., Yang, Q., & Chen, S. (2021). Microbial mediation of phosphorus dynamics at the sediment–water interface. *Science of the Total Environment*, 755, 142553.
- Mortimer, R. J. G., Krom, M. D., Watson, P. G., Frickers, P. E., & Davey, J. T. (2020). Sediment–water exchange of nutrients in shallow water systems: Influence of pH and redox conditions. *Marine Chemistry*, 223, 103817.

- Reddy, K. R., & D'Angelo, E. M. (1997). Biogeochemical indicators to evaluate pollutant removal efficiency in constructed wetlands. *Water Science and Technology*, 35(5), 1–10.
- Wang, J., Chen, L., & Zhou, X. (2022). Human-induced changes in sediment–water interactions and nutrient dynamics in reservoirs. *Aquatic Sciences*, 84(3), 59–73.
- Wetzel, R. G. (2001). *Limnology: Lake and River Ecosystems* (3rd ed.). Academic Press.
- Zhang, L., Wang, X., & Guo, Y. (2019). Nutrient dynamics and sediment–water interactions in freshwater ecosystems: A review. *Environmental Science and Pollution Research*, 26, 21944–21956.
- Zhou, Y., Huang, S., & Chen, Z. (2018). Microcosm experiments for studying sediment–water nutrient exchanges under variable environmental conditions. *Ecological Engineering*, 120, 187–196.



IMPORTANCE OF VALUE ADDITION IN AONLA IN PRATAPGARH DISTRICT OF UTTAR PRADESH

Article ID: AG-VO5-I12-74**Ishita Omar¹, Supriya^{1*}, Pradeep Mishra² and Prateek Kumar³**

¹Department of Agricultural Economics, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya

²Department of Agricultural Statistics, College of Agriculture REWA, Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, Madhya Pradesh

³Department of Agricultural Extension Education, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, India

*Corresponding Author Email ID: drsupriya.anduat2019@gmail.com

Abstract

Tomato (*Solanum lycopersicum* L.) and aonla (*Emblica officinalis* Gaertn.) are two economically important horticultural crops in Uttar Pradesh that contribute significantly to farmers' livelihoods, nutrition security and agro-based industries. Despite their high production potential, both crops suffer from acute post-harvest losses, glut-season price crashes and weak farmer participation in value addition. This study examines the importance of value addition in tomato and aonla with equal emphasis, drawing empirical insights from Varanasi district for tomato and Pratapgarh district for aonla. During peak harvest periods, tomato prices decline sharply to ₹6–10 per quintal, while aonla prices fall to ₹16–20 per quintal, forcing farmers into distress sales. The existing marketing systems are dominated by intermediaries, processors and retailers, who capture a major share of the consumer price, whereas farmers receive only a marginal return. Both tomato and aonla possess strong potential for conversion into diverse value-added products such as sauces, purees and powders from tomato, and candy, murabba, juice, powder and nutraceutical products from aonla. Value addition enhances shelf life, reduces post-harvest losses, stabilizes prices and creates opportunities for income diversification and export.

Keywords: Tomato, aonla, value addition, post-harvest management, price volatility

Introduction

Horticulture has emerged as a key driver of agricultural diversification and income enhancement in India. Among horticultural crops, Tomato (*Solanum lycopersicum* L.) and Aonla (*Emblica officinalis* Gaertn.) occupy an important place due to their wide cultivation, nutritional value and processing potential. However, both crops are characterized by high perishability and seasonal concentration of production, making farmers vulnerable to price instability and market inefficiencies. Tomato is one of the most widely cultivated vegetable crops in the country and forms an essential component of daily diets. It is rich in lycopene, vitamins and minerals and has extensive industrial applications. Owing to its high moisture content and soft texture, tomato is highly perishable and prone to rapid deterioration after harvest.

During peak production periods, excessive market arrivals lead to sharp price declines, often resulting in distress sales by farmers (Geetha & Rani, 2020; Adeoye & Aderibigbe, 2021). Aonla, popularly known as Indian gooseberry, is a fruit crop of immense nutritional and medicinal significance, particularly valued for its exceptionally high vitamin C content and antioxidant properties. It is widely used in Ayurvedic and nutraceutical preparations. Despite these advantages, aonla remains underutilized in fresh markets due to its astringent taste and limited fresh consumption. Processing and value addition are therefore crucial for unlocking its economic potential (Kore et al., 2013; Rekha, 2009).

1.2 Study Area and Data Collection

The study is based on field-level observations and secondary information collected from two major horticultural districts of Uttar Pradesh.



Fig 1: Tomato cultivation in Varanasi district of Uttar Pradesh

Tomato-related data were collected from Varanasi district, an important vegetable-producing region supplying local and nearby urban markets. Aonla-related data were collected from Pratapgarh district, which is recognized as one of the major aonla-producing belts in India. These districts were selected to represent typical challenges associated with marketing, price volatility and limited farmer participation in value addition for perishable horticultural crops

1.3 Glut-Season Price Crash in Tomato and Aonla

Price volatility during the harvesting season is a common challenge for both tomato and aonla farmers. In Varanasi district, tomato prices during glut periods often fall drastically to ₹6–10 per quintal, making cultivation economically unviable. Similarly, in Pratapgarh district, aonla prices decline to ₹16–20 per quintal during the peak harvesting season. Such low prices fail to cover production and harvesting costs, compelling farmers to sell their produce immediately after harvest.



Fig 2: Aonla harvesting in Pratapgarh district of Uttar Pradesh

In the case of aonla, many farmers lease out their orchards to contractors on a contract basis. For one *bheja* of land, returns range from ₹40,000 to ₹80,000 depending on the age and productivity of the orchard. Older orchards yield higher production and therefore attract higher contract values. While this system provides assured income to farmers, it limits their participation in processing and marketing, thereby restricting long-term income growth.

1.4 Marketing Channels and Distribution of Value

The marketing systems of tomato and aonla are characterized by the dominance of intermediaries. In the case of aonla, the prevalent marketing channel is:



A similar structure exists in tomato marketing, where farmers sell fresh produce to traders or processors during the glut season. Contractors, processors and retailers capture the highest profit margins by converting raw produce into processed products. Aonla-based processed products are sold at prices as high as ₹200 per kg, while tomato-based products such as ketchup, sauces and purees fetch premium prices in urban markets. In contrast, farmers receive only a small share of the final consumer price, highlighting inequitable value distribution in both crops.

1.5 Potential of Value Addition in Tomato and Aonla

Both tomato and aonla have immense potential for value addition, which can significantly enhance profitability and reduce post-harvest losses. Tomato can be processed into ketchup, sauces, pastes, purees, juices, powders and chutneys, thereby improving shelf life and enabling year-round market supply (Thakur et al., 1996; Silva et al., 2023). Similarly, aonla can be transformed into a wide range of products such as candy, murabba, juice, powder, chawanprash, flavored barfi and laddus. These products have strong domestic and export demand due to their nutritional and medicinal attributes (Jat et al., 2020; Prajapati et al., 2011). Value addition in both crops not only stabilizes prices but also generates employment opportunities, particularly for rural women, and contributes to income diversification and nutritional security (Tripathi et al., 2017).

1.6 Role of Value Addition in Enhancing Farmer Income

The absence of on-farm and community-level processing facilities forces tomato and aonla farmers into a vicious cycle of low income and low investment. Promoting value addition through farmer producer organizations (FPOs), self-help groups (SHGs) and cooperative models can enable farmers to retain a larger share of the consumer price. In addition, value-added products have longer shelf life, lower transportation losses and better access to organized retail and export markets. Food safety and quality assurance play a crucial role in value addition. Obtaining FSSAI licensing enhances consumer trust, improves product credibility and increases market value. Certified products command higher prices and enable entry into national and

international markets, thereby strengthening the economic resilience of tomato and aonla farmers.



Fig 3: value added products like pickle, barfi, laddu, candy etc sold in market

Conclusion

Tomato and aonla represent two contrasting yet comparable cases of horticultural crops in Uttar Pradesh that suffer from similar structural and market-related challenges. Despite their high nutritional value, production potential and suitability for processing, farmers cultivating these crops continue to face severe income instability due to glut-season price crashes, perishability and limited access to value addition opportunities. Evidence from Varanasi district for tomato and Pratapgarh district for aonla clearly indicates that farmers primarily operate at the lowest end of the value chain, while intermediaries, processors and retailers capture a disproportionate share of the consumer price. The study highlights that value addition is a critical pathway for transforming tomato and aonla cultivation from low-return primary production to a remunerative agribusiness activity. Addressing this requires targeted interventions such as strengthening post-harvest and processing infrastructure, promoting farmer-led enterprises through FPOs and SHGs, improving access to credit and skill development, and enhancing awareness about food safety and quality standards. Regulatory compliance, especially FSSAI licensing, can further improve product credibility, market access and export potential. Integrating value addition into the production and marketing systems of both tomato and aonla is essential for ensuring sustainable income growth, reducing market risk and enhancing the overall

resilience of horticultural farmers in Uttar Pradesh. Policy support aimed at decentralized processing, capacity building and market linkages can play a decisive role in enabling farmers to capture greater value and achieve inclusive growth in the horticulture sector.

References

- Adeoye, I. B., & Aderibigbe, O. R. (2021). Economics of value addition in tomato. *Nigerian Journal of Horticultural Science*, 25(3), 74–79.
- Geetha, P., & Rani, C. I. (2020). Post-harvest technology and value addition of tomatoes.
- Geetha, K. S. (2011). *Value Chain Analysis of Tomato: A Study in Karnataka* (Doctoral dissertation, University of Agricultural Sciences, GKVK).
- Jat, M., Shivran, J., & Jat, R. P. (2020). Commercial products of aonla fruits, increasing the value addition. *Journal of Pharmacognosy and Phytochemistry*, 10, 1331–1337.
- Kore, V. T., Devi, H. L., & Kabir, J. (2013). Packaging, storage and value addition of aonla, an underutilized fruit, in India. *Fruits*, 68(3), 255–266.
- Prajapati, V. K., Nema, P. K., & Rathore, S. S. (2011). Effect of pretreatment and drying methods on quality of value-added dried aonla shreds. *Journal of Food Science and Technology*, 48(1), 45–52.
- Rekha, G. (2009). *Processing of Aonla Fruits for Value Addition* (Doctoral Dissertation, University of Horticultural Sciences, Bagalkot).
- Silva, F. D., dos Santos Garcia, V. A., Vanin, F. M., Yoshida, C. M. P., & de Carvalho, R. A. (2023). Application of tomato byproduct in food products—A review. *Food Science and Engineering*, 4, 103–115.
- Thakur, B. R., Singh, R. K., & Nelson, P. E. (1996). Quality attributes of processed tomato products: A review. *Food Reviews International*, 12(3), 375–401.
- Tripathi, S. P., Patel, R. P., Somvanshi, S. P. S., Singh, H. P., & Dubey, B. (2017). Impact of value-added tomato-based products for income generation of farm women.

KALANAMAK: A HERITAGE RICE'S JOURNEY FROM A REMOTE VILLAGE TO THE GLOBE

Article ID: AG-VO5-I12-75***R. C. Chaudhary, Pushker Chauhary, A. K. Srivastava and Pradeep Yadav**

Participatory Rural Development Foundation, 59 Nahar Road, Gorakhpur 273014, U. P., India,

*Corresponding Author Email ID: ram.chaudhary@gmail.com,

Summary

Kalanamak, a landrace of rice (*Oryza sativa* L.), often referred to as “Buddha Home Rice” or ‘Buddha Rice,’ holds a significant place in the cultural and agricultural history of India. This heritage rice variety is believed to be blessed by Lord Buddha himself to the farmers of Bajaha village in Siddharthnagar district of U. P., some 3000 years ago. Facing extinction but due to the *Bhagirath Prayas* of one scientist, now touching the world market. parts of programme involved germplasm collection, followed by the pureline selection, hybridization and selection, and modern revival to reach to global level. Historically prized for its unique fragrance, taste, and nutritional benefits, Kalanamak rice saw a decline during the Green Revolution due to its lower yield compared to modern rice varieties.

However, the success of Kalanamak rice faces challenges, particularly in ensuring authenticity and quality control amidst the proliferation of counterfeit products. Advanced technologies such as blockchain and QR code-based traceability systems are proposed to combat these issues. Sustainable agricultural practices, ongoing research, and innovations are emphasized as crucial for the continued growth and environmental viability of Kalanamak rice cultivation.

1. Historical Significance and Cultural Tale of Kalanamak rice

The history of Kalanamak rice is deeply intertwined with the local myths and cultural practices of the region. According to legend [16], [53]; [59], Lord Gautam Buddha, after he received enlightenment, was returning from Bodha Gaya to his father’s kingdom in Kapilvastu, he was requested by the villagers of Bajaha jungle (now Bajaha and Mathala villages) to bless them. He then took out a fist of paddy seeds from his bag and asked them to grow these in the lowland.

The fragrance of the rice will remind them of Him and the nutritive value as His blessing. This story has not only persisted but has also become a part of the local folklore, enhancing the cultural significance of Kalanamak rice [7], [16].

2. Decline to near extinction of Kalanamak

The decline of Kalanamak rice cultivation can be attributed to several socio-economic and technical factors. Basically, there were four major reasons for the decline of the Kalanamak area. First was the advent of High Yielding Varieties (HYV) of rice in 1965, which yielded double Kalanamak. The second reason was the absence of any improved variety of Kalanamak which had become a Land Race and admixture. The third reason was the neglect of Kalanamak by the research and academic institutions [21], [22]. The fourth reason was the loss of aroma and grain quality due to unscientific seed production. The sum of all the factors reduced the Kalanamak area (Table 1).

3. Organized Improvement of Kalanamak rice

Organized efforts to improve Kalanamak did not start until 1974 [54], though the Department of Agriculture did try to test some Kalanamak germplasm at their research centers. The first organized efforts started at G. B. Pant University of Agriculture and Technology, Pantnagar with the start of Mutation Breeding [1], [2]. Not much could be achieved except getting some mutants of academic interest in Kalanamak [17]. Later Pantnagar did try testing some germplasm of Kalanamak but nothing of use could come out.

3. Germplasm Collection and Evaluation of Kalanamak

Before the germplasm collection of Kalanamak was formally started, some preliminary work on inducing mutation in Kalanamak rice was done at G. B. Pant University of Agriculture and Technology, Pantnagar [1], [2], [34]. Organized germplasm collection was done with financial assistance from the U . P. Council of Agricultural Research (UPCAR) described below [16].

3.1 Germplasm Collection: A collection of Kalanamak germplasm was done in order to get some superior types for further varietal improvement programmes. The germplasm was collected as a single panicle collection and bulk collection from sources like farmers' fields and research institutions [5], [20], [18], [19]

The single panicle collections were used for developing purelines and bulk collections were tested for yield potential.



Fig.1.Polished rice of Kalanamak Kiran



Fig. 2. Unpolished Kalanamak Kiran rice



Fig. 3.Kalanamak KN 3 (2m tall) as the first variety of Kalanamak



Fig. 4. My grandson Kiran in the field of Kalanamak Kiran variety (95 cm dwarf)

3.2 Single Panicle Collection :

A total of 1,455 panicles were collected from farmers' fields of Maharajganj, Sant Kabir Nagar, and Siddharth Nagar districts. These panicles were tested organoleptically for aroma and classified as aromatic and -non-aromatic types. Only 12.57% of panicles were found aromatic (belonging to 5 accessions), and the rest 87.43% were non-aromatic. Aromatic types were sown

in nursery beds using the concept of the panicle-to-row method. Seedlings from one panicle were transplanted in a single row.

Observations on initial and 50% flowering, tillering ability, maturity, etc. were recorded. Initial flowering ranged between 100 to 108 days and 50% flowering ranged between 104 to 114 days. Maturity duration ranged between the ranges of 134 to 144 days. Superior performing and scented lines were identified, and 5 single plants were harvested separately. The frequency of aromatic lines for each accession is provided in Table 2.

Table 2 reveals that from the 226 lines out of five accessions only 70 lines were found to be aromatic (33.58%) in the current cropping season. Thus there has been improvement as the frequency of aromatic lines has been doubled in one cycle of selection only. Therefore, it is expected that in the next two cycles, pure aromatic lines could be developed. Further, the stability of the aroma of such pure lines of Kalanamak in various locations could then be tested.

3.3 Bulk Collection :

A total of 39 bulk collections were collected from different sources. Out of these, 16 collections were from PRDF Gorakhpur; 8 collections from NDUAT, Ayodhya, and 15 collections from CRRI, Cuttack. These collections were tested in a randomized block design (RBD) using a multi-location trial with 2 replications in 4 districts. The trials were arranged at the following locations.

PRDF experimental plot	(Gorakhpur)	★ ★ ★ ★ ★
Sampatiha	(Maharajganj)	
Jhingurapar	(Sant Kabir Nagar)	
Ghoswa	(Siddharthnagar)	

In these purposely delayed sowing trials, observations for seedling height, and seedling vigour were recorded at the seedling stage. Just before transplanting, average heights ranged from 33 to 38 cm. Vigour was normal but KN 38, 41, and 42 were more vigorous. Since the experiment could be planted late, initial flowering ranged between 87 to 93 and 50% flowering ranged between 91 to 101 days. Maturity duration ranged between 121 to 131 days and other characters ranged too (Table 3).

The mature crop was harvested and yield data of each accession for each location was recorded. The data were analyzed to find out accessions with superior yield potential using ANOVA. After analysis, KN 53, 55, and 56 were found significantly superior at all the locations

over the rest of the accessions. However, KN 48, 54, and 58 were found significantly superior only at two locations. Thus finally KN 48, 53, 54, 55, 56, and 58 had been selected for better yield potential from a total of 39 accessions. Also, visually superior panicles from each accession were collected for further study.

All these accessions have National Accession Number [24]. Details are described in the Catalogue and publications [5], [24]; [20], [33], [18], [19], and [7]. One set of these collections were also sent to Directorate of Rice Research (DRR) Hyderabad and Central Rice Research Institute (CRRI), Cuttack for conservation and use at their ends [25], [26], [27], and [28].

4. Breeding of Kalanamak KN 3

As per procedure, any crop variety to be released for general cultivation in Uttar Pradesh must be tested by the Department of Agriculture at their Regional Agricultural in Testing and Demonstration Stations (RATDS) for three years. Pureline selection of Kalanamak (KN3-27-3 - 3) was tested from 2004 to 2007. Based on its superior performance it was released by U. P. State Variety Recommendation Committee in 2007 as Kalanamak KN3. However, it was notified by the Central Sub Committee on Varietal Release and Notification in 2010. KN 3 was the first Kalanamak rice variety developed through Pureline selection and set a historic platform with original aroma and grain quality [36], [8]. KN 3 became popular with farmers and will remain popular in the low-lying areas where water stagnates for more than half a meter. Its characters are summarised in Table 4.

Farmers and consumers realized that the aroma and grain quality of Kalanamak have returned back in KN 3 [8], [9], [10], [11], [12], [13], [14], and [15]. Since the variety Kalanamak KN3 was released and notified on the proposal of PRDF Gorakhpur, we retain the exclusive right to produce Nucleus Seed and Breeder Seed [9]. Other organizations like National Seeds Corporation, U. P. Beej Vikas Nigam, and others produce Certified Seed of it. A package of practices for the cultivation of Kalanamak was standardized and publicity was done by All India Radio, Door Darshan, in Indian Farming, Kheti, Rice India, and other popular magazines [6], [25], [26], [27], [28]; and [9].

5. Breeding of Bauna Kalanamak 101

Regional Agricultural Technology Demonstration & Testing Station (RATDS) of the Department of Agriculture conducts varietal trials annually on the new varieties to be considered for release. PRDF had proposed a number of semi-dwarf breeding lines of Kalanamak. These

breeding lines were tested at RATDS during the years 2012 to 2014 in a state trial called “Paddy standard varietal trial: Sthaniy Sugandhit”. The yields and morpho-agronomic characters taken from the three RATDS located in the Eastern Region of U. P. are given in Table 5 [23].

Based on the superior performance of UPCARKN-2-19-14 was proposed for release in the State Variety Release Committee in 2015. Farmers have liked it and it was already cultivated in more than 2,000 acres during Kharif 2014. Yields were very high but the grain quality characters of Bauna Kalanamak 101 were analyzed and found to be a bit different from the tall Kalanamak KN3. The husk colour was brownish, not black, and also grain was a bit coarser than KN3. However, due to yield advantage farmers liked it and expanded the area [50], [51], [52], [37], [38]. The aroma quantification was done by IICT Hyderabad and the results are reproduced below.

6. Breeding of Bauna Kalanamak 102

A proposal for the release of Bauna Kalanamak 102 was put up once the U. P. State Variety Release Committee released it in 2017. Yields obtained at RATDS and morpho-agronomic characters observed from 2013 to 2015 are summarised in Table 6. Bauna Kalanamak 102 was a definite improvement on the grain characters of Bauna Kalanamak 101. That is how it became more popular with the farmers and consumers [50], [51], [52].

7. Breeding of Kalanamak Kiran

Kalanamak Kiran was derived from a cross of KN 3 and Swarna Sub₁. The segregating generations were handled by the Pedigree method of breeding and selection. The breeding line was purified as PRDF-2-14-10-1-1 and tested as PRDF-2-14-10 and the pedigree line PRDF-2-14-10 was tested at RATDS of the Department of Agriculture during 2013 – 2016. It stood at first rank with an average yield of 32.95 quintal/ha. It out-yielded the check variety Kalanamak KN3 by 26.58 %. On average PRDF-2-14-10 out-yielded the check variety Kalanamak KN3 by 26.58%. Over the second check variety Lalmati, it out-yielded by 25.23 %. In AICRIP trials as the IET No. 27453 in AICRIP trials, it out-yielded the check variety Kalanamak KN3 by 33.35% across the country. It is semi-dwarf, lodging resistant, and suitable for harvesting by combine harvester (Table 7). On the date of the planting trial, it was established that a seed sown in the -mid-June and transplanted in -mid-July is the best for its performance and yield (Table 8) as it is a highly photoperiod sensitive variety, and inherited from its Kalanamak parent. The resistance to pests and disease is acceptable, as compared to the other varieties of the group (Table 9).

The grain quality was tested in the Regional Food Analysis and Research Centre (R-FRAC) at Lucknow, and in the Asia Pacific Lab in Singapore (Table 10). PRDF-2-14-10 has the same black husk, white and aromatic rice grain with excellent cooking quality, as the original Kalanamak KN3. Its aroma content was confirmed by the Indian Institute of Chemical Technology (IICT), Hyderabad through sophisticated tests. Its aroma content was confirmed by the Indian Institute of Chemical Technology (IICT), Hyderabad confirmed its aroma equal to KN3. Kalanamak Kiran has the same level of Iron and Zinc as its original parent Kalanamak KN3 [42], [43], [44], [45], and [46].

Compared to its 200 cm tall parent KN3 (Fig. 1), PRDF-2-14-10 (Kalanamak Kiran) is semi-dwarf (height 95 cm (Fig. 2), highly resistant to lodging and shattering, and is suitable for harvesting by combine harvester. PRDF-2-14-10 (Kalanamak Kiran) matures earlier than Kalanamak KN3 by about 10 days. This early maturity enables planting of the following Rabi crop earlier, by 10 days. Therefore, PRDF-2-14-10 was found superior to the checks in all these tests and was recommended for release as Kalanamak Kiran by the U. P. State Variety Release Sub-Committee in its 56th meeting held on 19th May 2017 at Lucknow. Based on the above superior features of PRDF-2-14-10, the U. P. State Variety Release Sub-Committee proposes that PRDF-2-14-10 should be released and notified as Kalanamak Kiran for eastern Uttar Pradesh. It was notified by the Government of India Gazette of India under Gazette No. 3220 (Part II (3) dated 06.08.2019.

8. Kalanamak Rice: Key Feature

8.1 Unique grain Quality attributes and pleasant Aroma

Kalanamak rice is distinguished by its unique black husk and white rice (Fig. 3), and greenish kernel if unpolished (Fig.4). extraordinary fragrance. The name "Kalanamak" is derived from two words: "Kala" meaning black and "Namak" meaning salt, referring to the black husk, and Namak referring to marshy soils that contain salt. Its palatability is excellent when cultivated in this particular soil. The aromatic quality of Kalanamak rice is one of its most celebrated features. This fragrance is attributed to the presence of a compound called 2-acetyl-1-pyrroline, which is also found in other aromatic rice varieties like Basmati and Jasmine. However, the concentration of this compound is higher in Kalanamak, making its aroma more pronounced [52].

The grain size of Kalanamak rice varies from short to medium, and it has a high elongation ratio when cooked. This means that the rice grains expand significantly upon cooking,

resulting in a fluffy and soft texture. The combination of its unique fragrance, texture, and mouth feel is the unique quality of Kalanamak. Kalanamak rice is a gourmet product, often sought after by connoisseurs of fine foods (Table 10).

The rice's aroma is so distinctive that it has been described in historical texts and local folklore as capable of attracting herds of deer from the jungle. This legend is not only a testament to its fragrance but also highlights the cultural importance of Kalanamak rice in the region.

8.2 Nutritional Properties

Kalanamak rice is not only prized for its aromatic qualities but also for its nutritional benefits. Studies have shown that Kalanamak rice is rich in micronutrients such as iron and zinc, which are essential for human health. The iron content in Kalanamak rice is significantly higher compared to other rice varieties, making it beneficial for preventing anaemia and other iron-deficiency disorders. The zinc content is also noteworthy, contributing to the rice's role in boosting the immune system and supporting metabolic functions (Table 10).

In addition to its micronutrient content, Kalanamak rice has a higher protein content than many common rice varieties. It contains about 11% protein, which is nearly double that of Basmati. This makes it a valuable food source, particularly in regions where protein intake might be limited. The rice also has a low glycemic index (GI), ranging between 49% and 52%, making it suitable for people with diabetes as it does not cause a rapid spike in blood sugar levels [55], [56], and [16].

The rice is also rich in antioxidants, which help in combating oxidative stress in the body. These antioxidants are crucial for preventing chronic diseases and promoting overall health. The presence of beta-carotene in Kalanamak rice, which is not found in many other rice varieties, adds to its nutritional profile by providing Vitamin A, important for vision and immune function [47], [48], [49], [50], [51], [52]. The nutritional benefits of Kalanamak rice, highlight its superiority and value as a heritage crop variety (Table 10).

8.3 Comparison with Other Rice Varieties

When compared to other popular rice varieties, such as Basmati, Kalanamak rice holds its own due to its unique qualities. Basmati rice, known for its long grains and distinctive aroma, is often used in Indian and Middle Eastern cuisines. Jasmine rice, another aromatic variety, is popular in Southeast Asia [47], [48], and [49]. While both these varieties are highly regarded for their flavour and texture, Kalanamak rice surpasses them.

Firstly, the fragrance of Kalanamak rice is stronger and more lingering than that of Basmati or Jasmine. The higher concentration of 2-acetyl-1-pyrroline in Kalanamak rice gives it a more robust aroma. Secondly, the nutritional content of Kalanamak rice, particularly its higher levels of iron and zinc, provides health benefits that are not as prominent in Basmati or Jasmine rice (Tables 11, 12). Besides Kalanamak has a good amount of Vitamin A in the form of Beta Carotene. The quantity is more than that of Golden rice [15].

In terms of texture, Kalanamak rice is softer and fluffier when cooked, compared to the slightly firmer texture of Basmati. This makes it suitable for a variety of dishes, from simple boiled rice to more elaborate preparations. The elongation ratio of Kalanamak rice, although significant, is not as high as that of Basmati, which makes it less prone to breaking during cooking, thus retaining its shape and integrity better [56], [57], [58], and [16].

Economic factors also played a role in the decline. The lack of market support and the absence of premium pricing for Kalanamak rice made it less attractive for farmers. Over time, the focus shifted to more commercially viable varieties, leading to the near extinction of Kalanamak rice by the 1990s [15].

9. Geographic Indication (GI) Tag

In recognition of its unique qualities and historical significance, Kalanamak rice was awarded the Geographic Indication (GI) tag in 2013. This GI tag has been given for its association with 11 districts - Siddharthnagar, Kushinagar, Maharajganj, Gorakhpur, Bahraich, Balrampur, Basti, Deoria, Gonda, Sant Kabir Nagar, and Shravasti (Fig. 5). This tag is crucial as it helps in preserving the authenticity of the Kalanamak rice and protecting it from counterfeit products. The GI tag identifies Kalanamak rice with the specific region of Siddharth Nagar and its adjacent districts, thereby ensuring that only rice grown in this area can be marketed under the name 'Kalanamak'. [60], [61], [62], and [63].

The GI tag (Fig. 5) awarded to Kalanamak rice in 2010, and valid until 2030 (Fig.6), has also played a crucial role in its revival [35]. The GI tag protects the authenticity of the rice and serves as an inspiration for other regions and products [57], [60], [61], [62], [63].

10. Prosperity of Kalanamak Farmers

Due to poor yield, poor quality, and lesser income as compared to HYV rice, the area under Kalanamak had declined (Table 1). However, now with the availability of a better quality variety of Kalanamak KN3 and high-yielding ones like Bauna Kalanamak 101, 102, and

Kalanamak Kiran, those negatives have been annulled. The government announces a Minimum Support Price (MSP) for fine rice of around Rs. 2,020/ per quintal. However, most farmers can't get that rate due to various reasons and are compelled to sell their paddy at lower prices, around Rs. 1,500 per quintal. Compared to that, Kalanamak paddy sells between Rs. 3,500 to Rs. 4,500 /- per quintal. Thus, now Kalanamak farmers are tripling their income.

Protocol for producing Organic Kalanamak has been developed [32], [33], [35] that fetches 20 percent higher price. Common rice with an average yield of 40 qtl/ha can give a net profit of Rs.35,500. Kalanamak KN3 and Bauna Kalanamak can give an average yield of 25 and 55 quintals per ha respectively. This amounts to a net profit of Rs. 56,875 for KN3 and for Bauna Kalanamak varieties Rs. 88,750. The net profit thus will be double to triple (Table 13). This should bring prosperity to the farmers of eastern U.P., where Basmati cannot be grown legally due to GI restriction. Production of Organic Kalanamak further benefits organic farmers by as much as Rs. 1,10,000/- per ha, which amounts to tripling the Kalanamak farmers' income (Table 13).

11. Socio-Economic Impact

11.1 Increase in Cultivation Area and Production

The concerted efforts by farmers, scientists, and the government have led to a significant increase in the cultivation area and production of Kalanamak rice. From a mere few thousand hectares in the early 2000s, the area under Kalanamak rice cultivation has expanded to tens of thousands of hectares by 2023. This expansion has been driven by the adoption of improved varieties, better agricultural practices, and increased market demand [16].

The development of dwarf varieties like Bauna Kalanamak 101, Bana Kalanamak 102, and Kalanamak Kiran has been particularly instrumental in this increase. These varieties are more resistant to lodging and pests, offer higher yields, and are better suited to modern farming techniques. The introduction of these varieties, along with training and support provided by government and non-governmental organizations, has encouraged more farmers to switch to Kalanamak rice cultivation.

The increase in production has also been supported by improved government policies, infrastructure and market access. The establishment of processing and packaging centres, often managed by FPOs, has ensured that the rice is processed and packaged efficiently, maintaining its quality and appeal. Enhanced market access through both traditional and e-commerce

platforms has provided farmers with broader markets, ensuring better returns on their produce [50], [51], and [52].

12. Challenges for Future

12.1 Legal Protection to Kalanamak

The Protection of Plant Varieties and Farmers Rights Act (PPV & FRA) came into being in 2001. The scope and importance of the act is amply clear from its name. This gives the right to farmers to own, retain, sow, re-sow, and sell the seed of their varieties. Accordingly, we at PRDF helped the farmers of Siddharthnagar to get the registration of Kalanamak done under PPV & FRA on 8th April 2009. The registration assures that no individual or organization can steal the rights of the farmers of Kalanamak KN3 rice. It is protected until 30th August 2025 [8], [16].

PRDF also helped Kalanamak to get a Geographical Indication (GI) in 2010 covering 11 districts of eastern U. P. (Fig. 4). It expired in 2020 and once again, PRDF helped get the GI protection extended (Fig. 5) until 2030. Geographical Indication of Goods (GI) as the name implies, is an indication, in the form of a name or sign, used on the goods that have a specific geographical origin and possess qualities or a reputation that are due to the place of its origin. This was signed into an Act on 30th December 1999 by the President of India and enacted on 15th September 2003 [4]. GI protects the consumer and also safeguards the interests of the producers. The GI is perceived as both an origin and quality indicator because of which the consumer willingly pays a premium price, and producers make a bigger profit that leads to the growth of the regional economy. The importance and benefits of GI have been described well in the publications emanating from PRDF [3], [60], [61], [62], [63], [38], and [39]. Looking into all the benefits it would bring to Kalanamak as a commodity and Agro-climatic Zone No. 7 of Uttar Pradesh, its impact can well be imagined. GI for Kalanamak covers 11 districts namely Bahraich, Balrampur, Basti, Deoria, Gonda, Gorakhpur, Kushinagar, Maharajganj, Sant Kabir Nagar, Siddharth Nagar, and Shrawasti, located between Nepal border in the north to Ghaghra river in the south, Bahraich in the west to Deoria in the east (Figs. 4, 5). GI was registered for Kalanamak in August 2010 and published in the GI Journal of the Government of India, is now validated until 2030

12.2 Counterfeit and Adulterated Products

Despite the successful branding and commercialization efforts, Kalanamak rice faces significant challenges related to counterfeit and adulterated products. The high demand and premium pricing of Kalanamak rice have led to the proliferation of fake products in the market. Unscrupulous traders often mix Kalanamak rice with lower-quality varieties, or entirely counterfeit the product, misleading consumers and undermining the brand's reputation. The problem stems from the lack of any regulation to control it.

Efforts to combat counterfeit and adulterated products include the use of advanced technologies such as blockchain and QR code-based traceability systems. These technologies enable consumers to verify the authenticity of Kalanamak rice by scanning codes on the packaging, which provide detailed information about the product's origin, processing, and distribution. Such measures are essential to protect the integrity of the brand and ensure that consumers receive genuine Kalanamak rice [16].

12.3 Ensuring Authenticity and Quality Control

One of the most significant challenges facing Kalanamak rice is ensuring its authenticity and quality control. The high market value and growing demand for Kalanamak rice have led to an increase in counterfeit and adulterated products. These fake products undermine consumer trust and can severely damage the reputation of this heritage rice.

To combat this, advanced technologies such as blockchain and QR code-based traceability systems can be employed. Blockchain technology can provide a secure and immutable ledger of the entire supply chain, from farm to fork. By using blockchain, every transaction involving Kalanamak rice can be recorded, ensuring transparency and traceability. Consumers can scan QR codes on the packaging to verify the authenticity of the rice, and obtain detailed information about its origin, cultivation practices, and supply chain journey.

In addition to technological solutions, strengthening regulatory frameworks is crucial. Governments and regulatory bodies need to enforce stringent quality control standards and conduct regular inspections to ensure compliance. Certification schemes, such as the GI tag, must be rigorously implemented and monitored to prevent misuse. Public awareness campaigns can educate consumers about the importance of purchasing authentic Kalanamak rice and recognizing counterfeit products. To handle all these issues, the establishment of the Kalanamak Promotion Board has been mooted to the government in 2022. Their decision is long awaited [15], [16].

Collaboration between stakeholders, including farmers, government agencies, researchers, and businesses, is essential to develop and implement these measures effectively. Creating a robust system of checks and balances will help maintain the integrity of Kalanamak rice and protect it from fraudulent practices.

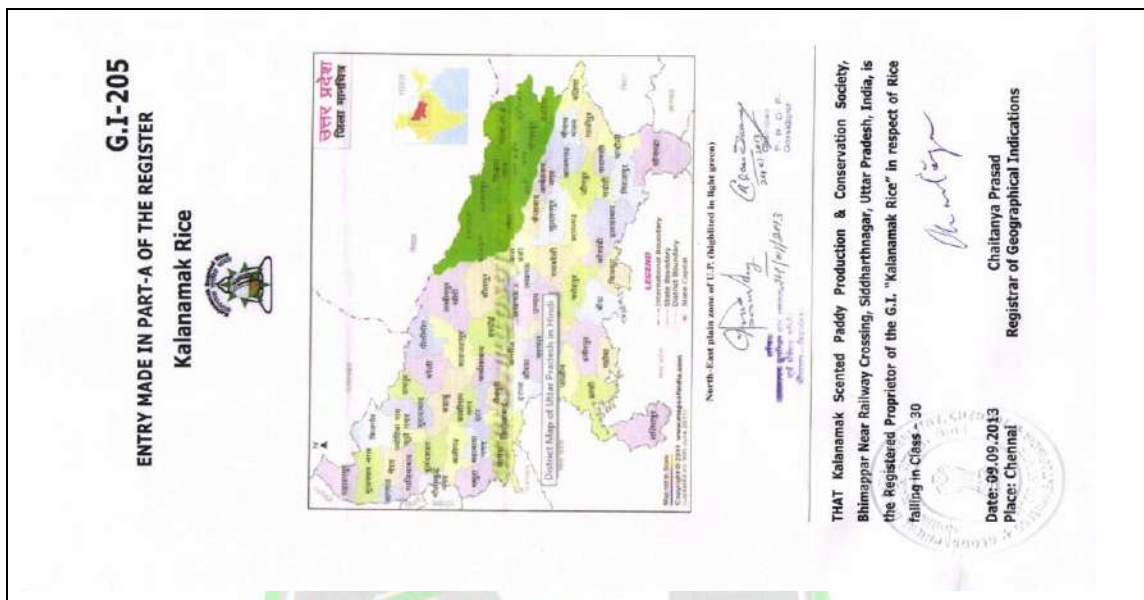


Fig. 5 Geographical Indication area of Kalanamak rice indicating 11 districts of U.P.



Geographical Indications Registry

Geographical Indications



INTELLECTUAL PROPERTY INDIA

Application Details	
Application Number	205
Geographical Indications	Kalanamak Rice
Status	Registered
Applicant Name	Kalanamak Scented Paddy Production & Conservation Society
Applicant Address	Bhimappur Near Railway Crossing, Siddharthnagar, Uttar Pradesh, India
Date of Filing	25-03-2010
Class	30
Goods	Agriculture
Geographical Area	Uttar Pradesh
Priority Country	India
Journal Number	50
Availability Date	07-05-2013
Certificate Number	194
Certificate Date	09-09-2013
Registration Valid Upto	24-03-2030

GI-Logo



Kalanamak Rice



Fig. 6 Geographical Indication of Kalanamak submitted in 2010 valid till March 2030

13. Expanding Market Reach

Expanding the market reach of Kalanamak rice involves both domestic and international efforts. While the rebranding as ‘Buddha Rice’ has been successful in attracting attention, continuous marketing and outreach are necessary to maintain and grow its consumer base. Targeted marketing campaigns that emphasize the unique qualities and historical significance of Kalanamak rice can help attract new customers. Participating in international food exhibitions and trade fairs can also showcase Kalanamak rice to a global audience.

In the domestic market, promoting Kalanamak rice through local and regional festivals, culinary events, and organic food markets can enhance its visibility and appeal. Collaborations with renowned chefs and food bloggers can create a buzz and highlight the rice’s exceptional culinary qualities [55]. Developing partnerships with retail chains and specialty stores can ensure that Kalanamak rice is available in premium outlets, catering to health-conscious and gourmet consumers [16], [18].

14. Summary of the Journey from Legend to Modern Revival

Kalanamak rice, often referred to as the ‘Buddha rice,’ boasts a fascinating journey that intertwines legend, history, and modern agricultural science. This aromatic rice variety, native to the Tarai region of Uttar Pradesh, India, has a storied past linked to Gautam Buddha, who is believed to have bestowed the rice upon the region's farmers. The legend says that Buddha, during his travels, gifted the villagers seeds of Kalanamak rice, blessing them with the promise that the rice would carry a fragrance that would remind them of him [16]. The historical cultivation of Kalanamak rice flourished for centuries, known for its distinct aroma, taste, and health benefits. However, the advent of the Green Revolution in the mid-20th century brought high-yielding, modern rice varieties that overshadowed traditional types like Kalanamak. Farmers began to abandon Kalanamak rice due to its lower yield and the intensive labour required for its cultivation, leading to a drastic decline in its acreage [57], [58].

The revival of Kalanamak rice began in the late 20th century, spearheaded by dedicated agricultural scientists and supported by government initiatives. Efforts focused on enhancing the rice’s agronomic traits while preserving its unique qualities. Dr. Ram Chet Chaudhary’s pioneering work in developing improved varieties such as KN3 and dwarf versions like Bauna Kalanamak 101, Bauna Kalanamak102, and Kalanamak Kiran played a crucial role in this revival. These varieties addressed issues of low yield and lodging, making Kalanamak rice more

viable for modern agriculture [7], [16]. The Geographical Indication (GI) tag awarded to Kalanamak rice in 2013 marked a significant milestone, protecting its authenticity and boosting its market appeal. Branding initiatives, particularly the rebranding as ‘Buddha Rice,’ and export efforts under schemes like the One District One Product (ODOP) have expanded its reach to international markets. Farmer Producer Organizations (FPOs) and e-commerce platforms have further facilitated the commercialization and distribution of Kalanamak rice, ensuring better returns for farmers and contributing to the regional economy.

In conclusion, the journey of Kalanamak rice from legend to modern revival is a powerful example of how traditional knowledge and modern science can come together to create sustainable solutions. By preserving the heritage of Kalanamak rice and promoting innovation, this unique rice variety continues to thrive and contribute to the well-being of farmers, consumers, and the environment.

Table 1. Area under Kalanamak rice [10,] [11], [12], [13], [14], and [34]

S.N.	Year	Kalanamak area (ha) estimate	Remark on technology and support
1	1960	50,000	The traditional area under Kalanamak
2	1970	40,000	The traditional area under Kalanamak
3	1980	10,000	Spread of HYV rice
4	1990	2,000	Spread of HYV rice
5	2000	2,000	Spread of HYV rice
6	2010	3,000	Release & Notification of Kalanamak KN3
7	2015	10,000	Release & Demonstration of Kalanamak KN3
8	2016	20,000	Release & Notification of Bauna Kalanamak 101
9	2017	25,000	Release & Notification of Bauna Kalanamak 102
10	2018	35,000	Release & Notification of Bauna Kalanamak 102
11	2019	40,000	Release & Notification of Kalanamak Kiran
12	2020	45,000	Release & Notification of Kalanamak Kiran

13	2021	50,000	Notification of Kalanamak Kiran, Govt. support as FPO, CFC, Mahotsav, exhibitions
14	2022	70,000	Govt. support, inspiration from the President Sri Ram Nath Kovind, PM Sri Modi Ji and CM Sri Yogi Adityanath Ji, MSME, Dept. Agriculture
15	2023	80,000	Govt. support, inspiration from the President Smt. Droupadi Murmu, PM Sri Narendra Modi and CM Sri Yogi Adityanath, MSME, Dept. Agric. U. P.

Table 2. Frequency of aromatic lines for each accession

S.N.	Designation of the accession	Number of lines		% aromatic lines
		Total	Aromatic	
1	KN 2	75	20	26.66
2	KN 3	34	14	41.17
3	KN 7	21	7	33.33
4	KN 20	29	12	41.37
5	KN 29	67	17	25.37
	Total	226	70	167.90
	Average			33.58

Table 3. Range of variation for different characters in bulk collection

S. N.	Characters	Range
1.	Initial flowering (no. of days)	87 – 96
2.	50% flowering (no. of days)	91 – 101
3.	Maturity (no. of days)	121 – 131
4.	Plant height (cm)	125 – 174.5
5.	Panicle length (cm)	22.6 – 29.6
6.	Yield (q/ha)	10.7 – 169
7.	No. of grain per panicle	141 – 262
8.	100-grain weight (gm)	1.4 – 2.5

9.	Grain length (mm)	6.0 – 7.8
10.	Grain width (mm)	2.0 – 3.0
11.	L/B ratio	2.1 – 3.5

Table 4. Morpho-agronomic and grain quality characters of Kalanamak KN3

Morpho-agronomic traits	Description	Grain Traits	Description
Basal leaf sheath colour	Green	Kernel length	5.76 mm
Tillering ability	Medium (20 tiller/hill)	Kernel width	2.18 mm
Days to 50% flowering	115 days (Photosensitive)	L/B Ratio	2.64 mm
Days to maturity	155 days (Photosensitive)	Grain type	Medium Slender
Culm angle	Slightly Open (45 ⁰)	Kernel colour	White
Leaf length	59 cm.	1,000-grain weight	15 grams
Leaf width	1.4 cm.	Hulling	80 %
Panicle length	31 cm.	Milling	75 %
Panicle type	Open	Head rice	70 %
Plant height	142 cm.	Alkali value	6 - 7
Aroma in plant	Highly scented	Volume Expansion	4.5 times
Apiculus colour	Brown (tawny)	Gel consistency	80 mm
Awning	Absent	Amylose content	22 %
Lemma, Palea colour	Purplish Black	Aroma in grain	Strong
Stigma colour	Purplish Black	Taste	Superb

Table 5. Morpho-agronomic and grain quality characters of Bauna Kalanamak 101 (UPCAR KN2-19-14)

Morpho-agronomic traits	Description	Grain Traits	Description
Basal leaf sheath colour	Green	Kernel length	5.76 mm

Tillering ability	Medium (20 tiller/hill)	Kernel width	2.18 mm
Days to 50% flowering	110 days (Photosensitive)	L/B Ratio	2.64 mm
Days to maturity	145 days (Photosensitive)	Grain type	Medium Slender
Culm angle	Slightly Open (45 ⁰)	Kernel colour	White
Leaf length	59 cm.	1,000-grain weight	15 grams
Leaf width	1.4 cm.	Hulling	80 %
Panicle length	29 cm.	Milling	75 %
Panicle type	Open	Head rice	70 %
Plant height	95 cm.	Alkali value	6 - 7
Aroma in plant	Highly scented	Volume Expansion	4.5 times
Apiculus colour	Brown (tawny)	Gel consistency	80 mm
Awning	Tip-awned	Amylose content	22 %
Lemma, Palea colour	Purplish Black	Aroma in grain	Strong
Stigma colour	Purplish Black	Taste	Superb
Stem strength	Very strong (non-lodging)	Yield	50 q/ha

Table 6. Morpho-agronomic and grain quality characters of Bauna Kalanamak 102 (UPCAR KN1-5-1)

Morpho-agronomic traits	Description	Grain Traits	Description
Basal leaf sheath colour	Green	Husk colour	Light-black
Tillering ability	Medium (20 tiller/hill)	Kernel length	5.76 mm
Days to 50% flowering	110 days (Photosensitive)	Kernel width	2.18 mm
Days to maturity	135 days (Photosensitive)	L/B Ratio	2.64 mm
Culm angle	Slightly Open (45 ⁰)	Grain type	Medium Slender

Leaf length	59 cm	Kernel colour	White
Leaf width	1.4 cm	1,000-grain weight	15 grams
Panicle length	31 cm	Hulling	80 %
No. of grains/panicles	400	Milling	75 %
Plant height	102 cm	Head rice	70 %
Aroma in plant	Highly scented	Alkali value	6 - 7
Apiculus colour	Brown (tawny)	Volume Expansion	4.5 times
Awning	Few spikelets tip-awned	Gel consistency	80 mm
Lemma, Palea colour	White – Green - P. Black	Amylose content	20 %
Stigma colour	White	Aroma in grain	Strong

Table 7. Morpho-agronomic and grain quality characters of Kalanamak Kiran (PRDF -2-14-10)

Morpho-agronomic traits	Description	Grain Traits	Description
Basal leaf sheath colour	Green	Kernel length	5.76 mm
Tillering ability	Medium (20 tiller/hill)	Kernel width	2.18 mm
Days to 50% flowering	110 days (Photosensitive)	L/B Ratio	2.64 mm
Days to maturity	135 days (Photosensitive)	Grain type	Medium Slender
Culm angle	Slightly Open (45°)	Kernel colour	White
Leaf length	59 cm	1,000-grain weight	15 grams
Leaf width	1.4 cm	Hulling	80 %
Panicle length	31 cm	Milling	75 %
No. of grains/panicles	400	Head rice	70 %
Plant height	95 cm	Alkali value	6 - 7
Aroma in plant	Highly scented	Volume Expansion	4.5 times
Apiculus colour	Brown (tawny)	Gel consistency	80 mm

Awning	Absent	Amylose content	20 %
Lemma, Palea colour	Green – Purple Black	Aroma in grain	Strong
Stigma colour	White	Taste	Soft, aromatic

Table 8. Effect of date of planting, date of flowering, and duration of KN3 and Kalanamak Kiran

S.N.	Date of sowing	Kalanamak Kiran		Kalanamak KN3	
		Date of flowering	Days to flowering	Date of flowering	Days to flowering
1	15 May	19 October	157	27 October	165
2	30 May	19 October	142	27 October	150
3	15 June	19 October	126	27 October	134
4	30 June	19 October	111	27 October	119
5	15 July	22 October	100	30 October	108
6	30 July	23 October	84	30 October	91

Table 9. Reaction of **Kalanamak Kiran** to major pests & diseases, Kharif 2014, 2015 [36]

S.N.	Diseases	Reaction	S.N.	Pests	Reaction
1	Bacterial blight	Mod. Resistant	1	Stem borer	Mod. Susceptible
2	Blast	Mod. Resistant	2	Brown Plant Hopper	Mod. Resistant
3	Sheath blight	Mod. Susceptible	3	Green Leaf Hopper	Mod. Resistant
4	Sheath rot	Mod. Susceptible	4	Gundhi bug	Susceptible
5	Tungro	Resistant	5	Leaf folder	Mod. Resistant
6	Bacterial Leaf Streak	Resistant	6	Caseworm	Mod. Resistant
7	Brown spot	Resistant	7	Root weevil	Resistant

Table 10. Grain quality characters of Kalanamak KN 3, Bauna Kalanamak 101, Bauna Kalanamak 102, and Kalanamak Kiran rice varieties (analyzed at NRRI Cuttack, NDUAT Ayodhya, ICAR-IIRR Hyderabad, IICT Hyderabad, and R-FRAC, Lucknow).

S.	Traits	Description of the variety

N.		Kalanamak KN3	Bauna Kalanamak 101	Bauna Kalanamak 102	Kalanamak Kiran
1	Method of Breeding	Germplasm / Pureline selection	Hybridization and selection	Hybridization and selection	Hybridization and selection
2	Year of release/notification	2007 / 2010	2015 / 2016	2016 / 2017	2019 / 2019
3	Published in the Govt. Gazette	No. 1816, (1), August 31, 2010	No. 2771, (23), November 24, 2016	No. 2458, (12), August 29, 2017	No. 2948, (8), September 6, 2019
4	Kernel length	5.76 mm	5.76 mm	5.76 mm	5.76 mm
5	Kernel width	2.18 mm	2.18 mm	2.18 mm	2.18 mm
6	L/B Ratio	2.64 mm	2.64 mm	2.64 mm	2.64 mm
7	Grain type	Medium slender	Medium slender	Medium slender	Medium slender
8	Kernel colour	White	White	White	White
9	1,000-grain weight	15 grams	15 grams	15 grams	15 grams
10	Hulling	80 %	80 %	80 %	80 %
11	Milling	75 %	75 %	75 %	75 %
12	Head rice	70 %	70 %	70 %	70 %
13	Alkali value	6 - 7	6 - 7	6 - 7	6 - 7
14	Volume Expansion Ratio	4.5	4.5	4.5	4.5
15	Gel consistency	80 mm	80 mm	80 mm	80 mm
16	Amylose content	21 %	22 %	22 %	21 %
17	Aroma	Highly aromatic	Aromatic	Highly aromatic	Highly aromatic
18	Iron (ppm) *	4.82	4.35	4.55	4.81

19	Zinc (ppm)*	16.97	14.35	14.55	16.37
20	Protein	10.64 %	10.50 %	10.64 %	10.64 %
21	Beta Carotene**	0.52 mg/100g	0.50 mg/100g	0.52 mg/100g	0.53 mg/100g

* All India average of 15 locations from AICRIP trials

** Analysis done at R-FRAC, Dept. of Horticulture, Govt. of U. P., Lucknow

Table 11. The nutritional benefits of Kalanamak rice (Source: IRRI – ISAEC, Varanasi)

Nutrients	Quantity per 100g	Health Benefits
Protein	11%	Essential for muscle growth, tissue repair, and enzyme/hormone production.
Iron	3.9 mg (too high conc.)	Vital for the formation of haemoglobin and prevention of anaemia.
Zinc	16.97 ppm	Supports immune function, DNA synthesis, and cell division.
Carbohydrates	68%	Provides a primary source of energy.
Dietary Fibber	3.50%	Aids in digestion and helps maintain bowel health.
Fat	0.50%	Essential for absorbing fat-soluble vitamins and providing energy.
Beta-carotene (brown rice)	0.53 mg (claiming more than golden rice)	Converted to Vitamin A in the body, important for vision and immune function.
Glycemic Index	49-52	A low glycemic index helps in maintaining stable blood sugar levels, making it suitable for diabetics.
Magnesium	25 mg	Important for muscle and nerve function, blood sugar control, and bone health.
Phosphorus	95 mg	Crucial for the formation of bones and teeth, as well as the body's use of carbohydrates and

			fats.
Vitamin B1 (Thiamine)	0.1 mg		Necessary for glucose metabolism and plays a key role in nerve, muscle, and heart function.
Vitamin B2 (Riboflavin)	0.03 mg		Important for growth, energy production, and the breakdown of fats, drugs, and steroid hormones.
Vitamin B3 (Niacin)	1.6 mg		Helps convert food into energy and is essential for healthy skin, nerves, and digestion.
Vitamin B6 (Pyridoxine)	0.5 mg		Involved in the creation of neurotransmitters and red blood cells, and helps maintain normal brain development and immune system function.

Table 12. Comparative grain quality characters of Kalanamak rice and Basmati rice.
(Analysed at R-FRAC, Dept. of Horticulture, Government of U. P., Lucknow)

S.N.	Parameter	Kalanamak	Basmati	Test method
1	Fat %	0.51	0.50	IS12711: 1989 RA2005
2	Protein %	10.6	5.8	IS 7219: 1973 RA
3	Total Ash %	0.32	0.32	FSSAI Manual 2016
4	Iron mg / 100 g	3.0	1.0	FSSAI Manual 2016
5	Zinc mg / 100 g	16.37	4.23	FSSAI Manual 2016
6	Amylose %	18.86	24.50	ICAR – IIRR Hyderabad
7	Glycemic Index	49 – 52 %	80 – 85 %	ICAR – IIRR Hyderabad
8	Vitamin A (β Carotene)	0.53	0.0	R-FRAC, Lucknow
9	Cooked rice softness	Soft	Hard	

Table 13. Comparative profitability of Kalanamak KN3, Bauna Kalanamak and Common rice, 2022-23 [15]

Item	Common rice	Kalanamak KN3	Bauna Kalanamak*	Organic Kalanamak*
Rice area (ha)	9,24,976	5,000	63,000	2,000
Average Yield (qtl/ha)	40	25	35	35
Selling price of paddy (Rs./qtl)	2,020	3,500	3,500	4,000
Gross Profit	80,000	87,500	1,22,500	1,40,000
Cost of Cultivation (Rs./ha)	44,500	30,625	33,750	30,000
Net profit (Rs./ha)	35,500	56,875	88,750	1,10,000
Incremental income in (Rs/ha)	0	21,375	53,250	74,750

* Bauna Kalanamak 101, Bauna Kalanamak 102, Kalanamak Kiran

References

1. Chaudhary, R. C. 1979a. Productive mutants in scented rice in Uttar Pradesh. Proc. Symp. Role of Induced Mutations in Crop Improvement. Sept. 10 - 13, 1979. BARC - OU Hyderabad, Abs. P.60.
2. Chaudhary, R. C. 1979b. Increasing the mutagenic efficiency of EMS in rice. Proc. Symp. Role of Induced Mutations in Crop Improvement. Sept. 10 - 13, 1979. BARC - OU Hyderabad,
3. Chaudhary, R. C. 2002. Consequences of WTO and Geographic Indicators on economics, production, trend and marketing of speciality rices. Proc. World Rice Commerce 2002 Conference; Beijing, China, 16 -18 September 2002; 20 pp
4. Chaudhary, R. C. 2003. Speciality rice of the world: Effect of WTO and IPR on its production trend and marketing. Jour. Food, Agriculture and Environment. Vol. 1(2): 34 – 41.
5. Chaudhary, R. C. 2005. India the Great Cradle of Rice. In: Rice Landscapes of Life. Eds. A. Ferrero and G. M. Scansetti; Edizioni Mercurio, Torino, Italy; 161 – 175, pp.

6. Chaudhary, R. C. 2009. Prospects of promoting traditional scented rice varieties of eastern U. P. for local consumption and export. *Rice India*; Vol. 19(8): 22 -24.
7. Chaudhary, R. C. 2014. Augmenting Traditional Knowledge for the Nature Conservation and Nutrition Security in eastern part of India. International Knowledge Sharing and Summer School Workshop. Organized by DAAD Germany and University of Chiangmai, Thailand. Abs.
8. Chaudhary, R. C. 2016. *Story of heritage rice Kalanamak: Extinction to distinction in eastern Uttar Pradesh. In: Research Interface: promoting Exportable Rice Varieties and Evolving a Sustainable Development Model. Edit. Dr. Chandrika Prasad, VARDAN, New Delhi, pp.: 49 – 67.*
9. Chaudhary, R. C. 2019. Intellectual Property and Breeders Right in India. In: Protecting Plant Breeders' Rights in Agricultural Research and Development. Proc. Conf. Bihar Agriculture University, Sabour, Bhagalpur, Bihar; PP; - 25:
10. Chaudhary, R. C. 2020a. Scent of Kalanamak paddy is returning: There is tremendous boom in the area. *First Eye News*. July 25, 1- 2 p.
11. Chaudhary, R. C. 2020b. Aroma of Kalanamak rice is returning back: Big jump in area. *TFI Post*: 1 – 2 P.
12. Chaudhary, R. C. 2020c. Rice Price Today: Aroma of Kalanamak rice is returning and big jump in area. *News Nation*: 1P. ★★☆☆
13. Chaudhary, R. C. 2020d. Aroma of Kalanamak rice is returning back: Big jump in area. *India Narrative*: 1 – 2 P.
14. Chaudhary, R. C. 2020e. Aroma of Kalanamak rice is returning back: Big jump in area. *Amrit Vichar*: 1 – 3 P.
15. Chaudhary, R. C. 2022. *Story of Kalanamak rice: Past, Present and Future*. BFC publications, Lucknow, India. ISBN. 978-93-5632- 355-1, Pages.183.
16. Chaudhary, R. C. 2023. *Kalanamak Dhan: Atit se Vartman*, (in Hindi). Army Press, Lucknow, India. pages 300.
17. Chaudhary, R. C. and Chauhan, J. S. 1979. Note on isozyme pattern of monogenic recessive vegetative mutant in Kalanamak rice. *Proc. Symp. Role of Induced Mutations in Crop Improvement*. Sept. 10 -2.

18. Chaudhary, R. C. and Mishra, S. B. 2010. Collection of unique rice germplasm from the cradle of rice (*Oryza sativa* L.) in Eastern Uttar Pradesh. In: Genetic Resources of Rice in India: Past and Present; Ed. S. D. Sharma. Today & Tomorrow's Printers, New Delhi, pages: 587 - 594.
19. Chaudhary, R. C. and Mishra, S. B. 2016. Development and use of organic protocol to promote Kalanamak rice (*Oryza sativa* L.) and its certification under PGS Mode. Current Advances in Agricultural Sciences. Vol. 8 (1): 28 – 31.
20. Chaudhary, R. C. and Prajapati, S. C. 2007. Rice in its original home: interwoven diversity of rice varieties, agro-ecosystems and farmers in Uttar Pradesh (India). In: Agro-Economical traits of Rice Cultivation in Europe and India. Eds. Aldo Ferrero and Francesco Vidotto, EU – ECCP, Edizioni Mercurio, Vercelli, Italy.
21. Chaudhary, R. C. and Tran D. V. (Eds.), 2001a. Speciality Rices of the World: Breeding, Production and Marketing, FAO, Rome, Italy; 358 pp.
22. Chaudhary, R. C. and Tran D. V. 2001b. Speciality rices of the world: A prologue. In: Chaudhary, R. C. and Tran D. V. 2001. Speciality Rices of the World: Breeding, Production and Marketing; FAO Rome, Italy; (eds. Chaudhary, R. C. and Tran, D. V.) p. 3 – 12.
23. Chaudhary, R. C. and Kumar, S. 2018. Bauna Kalanamak 101: New aromatic variety of heritage rice. FARM Journal. Vol. 2 (1): 31 – 37.
24. Chaudhary, R. C.; Prajapati, S. C. ; Chaudhary, N.; Anita; and Shukla, A. K. 2007. Diversity in rice, its cultivation and its uses in the area of its origin: Eastern Uttar Pradesh, India. In: Geographical Researches on Rice: A Comparative Analysis of Rice Districts in the European Union and India; 165 – 176 pp. In: Geographical Researches on Rice: A Comparative Analysis of Rice Districts in the European Union and India. Editors Davide Papotti and Carlo Brusa; EU – ECCP, Edizioni Mercurio, Vercelli, Italy.
25. Chaudhary, R. C., S. B. Mishra, D. N. Dubey and Pushker Chaudhary 2008a. Short-grained aromatic rice Kalanamak: its Export potential. Commodity Today, Vol. 1 (9): pages 28 – 29.
26. Chaudhary, R. C., S. B. Mishra and D. N. Dubey 2008b. Cultivation of new variety of rice Kalanamak". Indian Farming; Vol. 58 (6), September : 21 – 24.

27. Chaudhary, R. C., S. B. Mishra and D. N. Dubey 2008c. : Scented rice variety of new Kalanamak and its cultivation package (Hindi); Kheti; Vol.61 (6), September: 10 – 12.
28. Chaudhary, R. C., S. B. Mishra and D. N. Dubey. 2008d. Scented rice variety Kalanamak and its cultivation for better quality and high yield. Rice India, Vol. 18 (8): 23 -2 5.
29. Chaudhary, R. C., S. B. Mishra, D. N. Dubey and Pushker Chaudhary 2008e. Short-grained aromatic rice Kalanamak: its Export potential. Commodity Today, Vol. 1 (9): pages 28 – 29.
30. Chaudhary, R. C., S. B. Mishra and D. N. Dubey 2008f. : Scented rice variety of new Kalanamak and its cultivation package (Hindi); Kheti; Vol.61 (6), September: 10 – 12.
31. Chaudhary, R. C., S. B. Mishra and D. N. Dubey. 2008g. Scented rice variety Kalanamak and its cultivation for better quality and high yield. Rice India, Vol. 18 (8): 23 -2 5.
32. Chaudhary, R. C.; Gandhe, A. and Mishra, S. B. 2010a. Manual on organic production of Kalanamak rice. PRDF Gorakhpur, India; 45 pp.
33. Chaudhary, R. C.; Pandey, A.; Mishra, S. B.; Dubey, D. N.; Chaudhary, P.; and Kumar D. 2010b. In: Catalogue of Aromatic rices of Eastern Uttar Pradesh. Eds. R. S. Rathor and C. Prasad. U. P. Council of Agricultural Research, Lucknow, pp 180.
34. Chaudhary, R. C.; Mishra, S. B.; Yadav, S. K. and Jabir Ali 2012. Extinction to distinction: Current status of Kalanamak, the heritage rice of eastern Uttar Pradesh and its likely role in farmers' prosperity. LMA Convention Journal. Vol. 8 (1): 7 – 14.
35. Chaudhary, R. C., S. B. Mishra, and D. Kumar 2013. Organic Farming of Kalanamak rice (in Hindi). Kheti, Vol. 66 (1); April 2013; 3 – 6.
36. Chaudhary, R. C., Gandhe Abhay and S. B. Mishra 2014. Revised Manual on Organic Production of Kalanamak Rice (English & Hindi). PRDF, Gorakhpur, U. P. India, 64 pp. https://www.researchgate.net/publication/320696789_Revised_Manual_on_Organic_Production_of_Kalanamak_Rice.
37. Chaudhary, R. C., Kumar, Sunil, and Mishra, S. B. 2016. New variety of aromatic rice: Bauna Kalanamak 101 (in Hindi). *Kahaar*. (Vol. 1 & 2): 1 - 5.
38. Chaudhary, R. C.; Yadav, S. K and Kumar, Sunil. 2017a. Geographical Indications in Indian agriculture on the anvil. J. Bio. Innov. Vol. 6 (5): 790 – 816.

39. Chaudhary, R. C.; Yadav, S. K. and Sahani, A.. 2017b. Present status and potentiality of Geographical Indications registration in Uttar Pradesh. National Symp. on IPRs in Agriculture Sector, BBAU & UPCAR Lucknow. 4 – 14 p. 193 pp.
40. Chaudhary, R. C., Kumar, Sunil, and Mishra, S. B. 2017c. Recent variety of aromatic rice: Bauna Kalanamak 102 (in Hindi). *Kahaar*. (Vol. 1 & 2): 9 - 13.
41. Chaudhary, R. C.; Kumar, S. and Mishra, S. B. 2018. Sustainable Tripling of Farmers' Income by Improving Heritage Rice Kalanamak (Jorhat Conference) In: International Conf. Climate Change, Biodiversity and Sustainable Agric culture, Assam Agri University, Jorhat & PHSS, Lucknow 13 -1 6 Dec. 2018.
42. Chaudhary, R. C. ; Sahani, A. and Mishra, S. b. 2020a. *Kalanamak chawal ke jaivik kheti ke anubhav*. Krishi Manjusha. Vol. 2 (2) 13 – 17.
43. Chaudhary, R. C.; Mishra, S. B. and Sahani, Anjali 2020b. Sugar free, aromatic and Nutritious rice variety Kalanamak Kiran notified in 2019. Nature Times magazine. Vol.1 (April 2020). p. 31 -36.
44. Chaudhary, R. C.; Sahani, A.; Mishra, S. B. and Kumar, R. 2020c. "Kalanamak Kiran" Dan Sugandhit, Loha aur Zasta se Bharpur. Krishi Jagran, 27 April pp 4.
45. Chaudhary, R. C., Sahani, A.; Mishra, S. B. and Kumar, R. 2020d. Kalanamak Kiran variety of rice developed as Aromatic, Nutritious and Sugar Free. Indian Farmers' Digest. Vol. 53 : 4 - 8
46. Chaudhary, R. C.; Anjali Sahani; Mishra, S. B. and Kumar, Ravindra 2020e. "Kalanamak Kiran" Dhaan Sugandhit, Loha aur Zasta se Bharpur. Krishi Jagran, 27 April pp 4.
47. Chaudhary, R. C.; Singh, Smriti; Yadav, Ritima; Das, Swapna; and Sahani, A. 2022a. High beta carotene discovered in Kalanamak rice. 2022. Journal of AgriSearch Vol. 8 (4): 379 – 380.
48. Chaudhary , R. C.; Sahani, A. and Mishra, S. B. 2022b. Improvement of Local Germplasm of Kalanamak Rice to benefit Environment, Health and Wealth. Scientific Research Journal of Agriculture and Life Sciences, Vol. 2 (1): ISSN Print : 2788-9378 | ISSN Online : 2788-9386 / Website : <https://isrpgroup.org/srjals-32=2022/>
49. Chaudhary, R. C.; Sahani, A. and Mishra, S. B. 2022c. Gem from Local Germplasm of Kalanamak Rice for Environment, Health and Wealth. International Journal of Multidisciplinary Research and Development. Vol. 3 (2): 427 – 432.

50. Kumar, S.; Mishra, S. B. and Chaudhary, R. C. 2018a. Breeding Bauna Kalanamak 101 as a New Aromatic Variety of Heritage Rice for Uttar Pradesh. *International J. Sci, Environ and Tech.* Vol. 7(2): 580 – 590.
51. Kumar, Sunil; S. B. Mishra and R. C. Chaudhary 2018b. Breeding Bauna Kalanamak 102 as New Aromatic Variety of Heritage Rice from Uttar Pradesh. . *International J. Sci, Environ and Tech.* Vol. 7(5): 1690-1699.
52. Kumar, D., Chaudhary, R. C., & Singh, Y. 2024. Kalanamak rice: A heritage variety. *Asian Journal of Agricultural Extension, Economics & Sociology*, 42(2), 189-199. <https://doi.org/10.9734/ajaees/2024/v42i218327>.
53. Legge, James 2021. A Record of Buddhistic Kingdoms. Publ. Dagny, J. B. and Widger, David. www.gutenberg.org
54. Nanda, J. S.; Chaudhary, R. C.; Singh, J. P.; Singh, H. P.; and Gupta, M. D. 1974. Breeding for quality rice through induced mutation. *Proc. Symp. Use of Radiations and Radioisotopes in Studies of Plant Productivity.* Pantnagar, April 12 - 14, 1974. pp. 24-32.
55. Pandey, Shweta; Tripathi, Vaishnavi; Sahin, Atika, Sahin; and Dubey, Pallavi 2022. Food Products of Broken Kalanamak Rice. PRDF Manual 22-1, 38 pp. (Publ. Dr. R. C. Chaudhary, PRDF Gorakhpur 273014, India), www.prdf-agri.com
56. Singh, R. K. and Singh, U. S. 2005. Scented Rices of Uttar Pradesh and Uttaranchal. Kalyani Publishers, ISBN: 9788127223908.
57. Singh, R. K.; Sahai, V. N.; Sharma, R. N.; Singh, U. S.; Singh S. and Singh, O. N. 2001. Current status and future prospects of improving traditional aromatic rice varieties in India. In: *Speciality Rices of the World: Breeding, Production and Marketing.* (Eds. R. C. Chaudhary and D. V. Tran) pp. 80 – 87.
58. Singh, U S Singh; Singh, Neelam; Singh, H. N. ; Singh, O. P. and Singh, R. K. 2005. Rediscovering scented rice cultivar Kalanamak. *Asian History Foundation*, Vol. 9 (3). 211 – 219.
59. Watters, T. 1904 On Yuan Chwangs's Travels in India, Vol. I, II. Royal Asiatic Society, London, pages 401, 377.
60. Yadav, S. K.; Chaudhary, R. C. and Sahani, A. 2017a. Registration for Geographical Indication in Uttar Pradesh: Present status and future potential. *International J. Trend in Research & Development.* Vol. 4 (6): 48 – 57.

61. Yadav, S. K.; Chaudhary, R. C. and Sahani, A. 2017b. Geographical Indication and Registration for it in Uttar Pradesh, India: Present and Future Potential. . Jour. Bio Innovation. Vol. 6 (5): 790-81.
62. Yadav, S. K. ; Chaudhary, R. C. and Sahani, A. 2018. Geographical Indication and registration for it in Uttar Pradesh, India.: Present and Future Potential. International Journal of Research in Agricultural Sciences. Vol. 5 (1): 48 – 57: ISSN online 2348 – 3997.
63. Yadav, S. K; Chaudhary, R. C. ; Kumar, S. and Mishra, S. B. 2019. Breakthrough in Tripling Farmers Income Sustainably by Producing Kalanamak rice. Journal of Agri Search, Vol. 6(1): 1 – 5.



Volume: 05 Issue No: 12

ANTIBIOTIC RESISTANCE: A SILENT THREAT IN DAIRY FARMING AND THE RISE OF NATURAL ALTERNATIVES FOR SAFER MILK PRODUCTION

Article ID: AG-V05-I12-76***V.Ramakrishna and L.Vimalendran**

Assistant Professor, Tamil Nadu Veterinary and Animal Sciences University –
Krishi Vigyan Kendra Kundrakudi – 630 206, Sivaganga District, Tamil Nadu

*Corresponding Author Email ID: rkntanuv@gmail.com

Introduction

Milk production in India is more than an agricultural activity, it is a deep-rooted cultural tradition and the primary livelihood for nearly 80 million dairy households. India has proudly retained its position as the world's largest milk producer for over two decades. However, behind this success story lies an emerging, invisible crisis: the rapid rise of antibiotic resistance in dairy animals. Antibiotics have historically been the backbone of disease management in dairy herds, particularly in controlling mastitis, which remains the most economically devastating disease in dairy sectors worldwide. But today, the overuse and misuse of antibiotics threaten to dismantle decades of progress by giving rise to bacteria that no longer respond to treatments that once saved animals. The dairy industry's dependence on antibiotics is not accidental. Mastitis is widespread, painful, and economically damaging. Farmers often resort to quick antibiotic treatments, sometimes without veterinary prescription, laboratory diagnosis, or adherence to withdrawal periods. While antibiotics may temporarily suppress the infection, this repetitive and often indiscriminate use exerts selective pressure on bacteria. Over time, only those pathogens with mutations or resistance genes survive. These resistant strains multiply and become dominant within the udder environment.

What makes the problem more dangerous is that resistant bacteria do not remain confined to the infected udder. Milk acts as a direct vehicle for these organisms and more importantly, their resistance genes to leave the animal's body. Even if pasteurization kills bacteria, the DNA fragments carrying antibiotic resistance genes (ARGs) can survive and transfer their resistance to

harmless bacteria in the human gut. This makes milk a silent conveyor of antimicrobial resistance from farms to households. The situation becomes particularly complex in India due to unique socio-cultural and infrastructural factors. First, the consumption of raw milk or inadequately boiled milk remains common in rural India, increasing the risk of ingesting resistant pathogens. Second, the informal and unregulated milk supply chain allows contaminated milk to mix with clean milk, expanding the exposure risk. Third, antibiotics are widely available without veterinary prescription in many rural markets, leading to irrational use by farmers under pressure to keep animals productive.

Antibiotic resistance is no longer a veterinary problem alone. It has evolved into a One Health issue connecting animal health, human health, food safety, and environmental sustainability. Resistant bacteria in dairy farms can spread to soil, water sources, and human communities. According to the World Health Organization, antimicrobial resistance could cause 10 million deaths annually by 2050 if left unchecked. The dairy sector, being a major interface between animals and humans, will play a pivotal role in slowing or accelerating this crisis. With these rising concerns, there is an urgent need to redefine how dairy health is managed. Instead of blindly relying on antibiotics, the sector must adopt safe, evidence-based, holistic alternatives. Ethno-Veterinary Medicine (EVM), herbal therapeutics, non-steroidal anti-inflammatory drugs (NSAIDs), and antimicrobial peptides (AMPs) are gaining attention for their efficacy and safety. These natural or semi-natural approaches not only reduce antibiotic dependency but also protect milk quality, consumer health, and long-term farm sustainability.

HEALTH AND A VEHICLE FOR ANTIBIOTIC RESISTANCE

Milk is often described as the “mirror of the udder,” meaning its quality and microbial composition directly reflect the health of the mammary gland. When the udder becomes infected particularly in mastitis pathogenic bacteria rapidly multiply within the milk ducts and alveoli. These bacteria, especially *Staphylococcus aureus*, *Escherichia coli*, *Streptococcus agalactiae*, and *Pseudomonas* spp., are shed continuously into the milk. As a result, the milk produced by an infected udder carries a microbial profile far different from healthy milk. This contaminated milk becomes the first and most direct reservoir of pathogenic and antibiotic-resistant microorganisms within the dairy production chain. The biological danger does not end with the presence of bacteria alone. Milk is a nutrient-rich fluid, containing proteins, lactose, fats, minerals, and vitamins. These components offer an ideal environment for bacterial growth and survival. When

resistant bacteria enter this nutrient-rich medium, they not only survive but often multiply more rapidly. This means that even a single infected quarter of the udder can result in significant bacterial contamination of the entire milk batch, especially in bulk tank systems. Without proper detection, this contaminated milk may mix with milk from healthy cows, silently amplifying the risk.

Another layer of complexity arises from antibiotic resistance genes (ARGs) present in the milk. These genes, which are located in the bacterial chromosomes or plasmids, may remain intact even after heat treatments such as boiling or pasteurization. Unlike bacterial cells, DNA is relatively more stable and can withstand moderate heat. Therefore, although pasteurization kills pathogenic bacteria, the resistance genes they carry may continue to persist in the milk matrix. Once consumed by humans, especially in raw or partially boiled forms, these genes can interact with the host's gut microbiota and potentially transfer resistance traits to commensal bacteria. This mechanism known as horizontal gene transfer is considered one of the fastest pathways for the spread of AMR in human populations.

Raw milk consumption remains a widespread traditional practice in many Indian states. While consumers often perceive raw milk as “pure,” “fresh,” or “nutritious,” scientific evidence shows that raw milk from infected cows poses a high risk of transferring resistant bacteria. Children, pregnant women, and elderly people who are already vulnerable may be exposed to pathogens like MRSA or ESBL-producing *E. coli* directly through such consumption. Furthermore, raw milk's creamy consistency and mild sweetness often mask any signs of contamination, making detection difficult without laboratory tests. Milk handling practices also contribute significantly to the spread of resistant pathogens. In many rural settings, milking is done manually under suboptimal hygienic conditions. Milking utensils, hands, and storage containers can harbor bacteria. When contaminated equipment comes into contact with milk, resistant bacteria introduced from the environment or earlier milk batches can proliferate rapidly. Additionally, improper cooling during storage and transportation provides an ideal temperature range for bacterial growth, allowing resistant bacteria to multiply exponentially before reaching collection centers. Bulk tank milk studies from Europe and India have both confirmed that microbial contamination at the farm level often passes unnoticed. Modern sequencing technologies like whole metagenome sequencing (WMS) have revealed a diverse resistome (collection of resistance genes) in bulk tank milk sampled from various farms. These resistome

signatures often include genes for β -lactam resistance, tetracycline resistance, sulfonamide resistance, and fluoroquinolone resistance. The presence of such a wide range of resistance determinants in bulk milk demonstrates that AMR is not restricted to a single infected cow but can be a farm-wide or even district-wide issue.

Therefore, milk is not only a nutritional commodity but also a potential biological carrier of antibiotic-resistant organisms and genes. It becomes a critical interface between animal health and human health. Ensuring the production of clean milk requires not just hygienic practices but a deeper understanding of the role milk plays in AMR transmission. Recognizing milk as both a diagnostic indicator and a risk vector is essential for designing effective control strategies and adopting antibiotic alternatives.

HOW ANTIBIOTIC RESISTANCE DEVELOPS IN DAIRY FARMS

Antibiotic resistance in dairy farms does not emerge suddenly; rather, it evolves slowly and silently through years of selective pressure exerted by repeated antibiotic use. Every time an antibiotic is administered, it creates an environment where susceptible bacteria die but resistant bacteria survive. These resistant organisms possess genetic mutations or resistance traits that allow them to escape the drug's action. Over multiple treatment cycles, these resilient bacteria multiply, ultimately becoming the dominant population within the cow's udder, the farm environment, and even the milk supply chain.

A major driver of this resistance is the improper and frequent use of antibiotics in mastitis treatment. Mastitis is one of the most common and economically costly diseases in dairy cows. Due to its painful symptoms and the urgency to restore milk production, farmers often treat mastitis without veterinary consultation. In many cases, antibiotics are used indiscriminately without conducting culture and sensitivity tests to determine which drug is effective. As a result, the cow may receive broad-spectrum antibiotics that may not even act on the causative organism, thereby giving the pathogen a chance to adapt and develop stronger survival mechanisms. In many Indian dairy farms, antibiotics can be purchased over the counter without veterinary prescription. This easy accessibility leads to excessive use of the same group of antibiotics repeatedly, such as penicillins, tetracyclines, or cephalosporins. When a single antimicrobial class is used frequently, bacteria quickly learn to resist it through mechanisms such as enzyme production (e.g., β -lactamases), alteration of drug-binding proteins, or efflux pumps that expel

the antibiotic from the cell. Once these resistance mechanisms are acquired, they can be transferred across bacteria and persist in the environment for long periods.

One particularly dangerous mechanism through which bacteria develop resistance is horizontal gene transfer (HGT). Unlike vertical inheritance passing traits from parent to offspring HGT allows bacteria to exchange genetic material directly with other bacteria in the same environment, even across species. Plasmids carrying resistance genes such as *mecA*, *blaCTX-M*, *blaTEM*, *tet*, or *sul* can spread rapidly within the udder microbiome, farm soil, water, and manure. This means that a single resistant strain of *Staphylococcus aureus* or *E. coli* can act as a reservoir, sharing resistance traits with other bacteria and amplifying the overall resistance profile of the farm.

Sub-therapeutic dosing is another problem contributing to AMR. Farmers sometimes stop treatment prematurely once the visible signs of mastitis improve, even though the infection has not fully resolved. This incomplete treatment kills only the sensitive bacteria, while the partially resistant ones survive and proliferate. Similarly, giving lower-than-recommended doses to "save money" or using expired drugs reduces the antimicrobial pressure, encouraging bacteria to tolerate small concentrations of antibiotics and gradually become resistant to larger doses. Environmental contamination also plays a critical role. Antibiotics excreted through urine, dung, and milk residues enter the farm environment. In cow sheds, feed troughs, manure pits, and farm soil, these antibiotics maintain low but persistent concentrations that select for resistant bacteria. This environmental exposure creates a continuous cycle of resistance development, where bacteria are repeatedly challenged and thus genetically conditioned to withstand antibiotic presence. Resistant bacteria from the environment can re-infect cows, spread to calves, contaminate feed and water, and eventually enter milk.

Another overlooked factor is the failure to maintain withdrawal periods. When cows are treated with antibiotics, the drug residues remain in milk for several days. If farmers do not discard this milk as required, it enters the bulk tank and exposes other milk to antimicrobial residues. These low-level residues do not kill bacteria in the milk but instead allow them to develop tolerance and resistance. Over time, the entire bulk tank becomes a breeding ground for resistant bacteria. In essence, the development of antibiotic resistance in dairy farms is a multi-factorial process involving microbial adaptation, human practices, farm environment, and regulatory gaps. The combination of irrational antibiotic use, inadequate veterinary supervision,

resistance gene transfer, environmental contamination, and poor milk handling practices creates a perfect breeding ground for AMR. If these practices continue unchecked, the dairy sector risks entering a post-antibiotic era where common infections may become untreatable and milk safety severely compromised.

THE PUBLIC HEALTH DIMENSION OF ANTIMICROBIAL RESISTANCE (AMR)

Antimicrobial resistance (AMR) originating from dairy farms poses a serious and expanding threat to public health worldwide. While the issue initially appears to be limited to farm animals, resistant bacteria and their genes have a remarkable ability to move from cows to humans through multiple pathways—primarily through dairy products like milk. This phenomenon underscores the interconnectedness of animal health, food safety, and human well-being, making AMR a quintessential One Health challenge. The public health consequences of AMR are often severe, leading to longer illness durations, treatment failures, increased healthcare costs, and in extreme cases, death. One of the primary reasons AMR poses such a grave public health concern is the efficiency with which resistant bacteria travel across species boundaries.

When humans consume milk contaminated with antibiotic-resistant bacteria—or with heat-stable antimicrobial resistance genes—they expose their gut microbiota to harmful genetic elements. These genes can then be transferred to harmless bacteria inhabiting the human intestines, transforming them into resistant strains. This horizontal gene transfer is extremely dangerous because it allows resistance traits to proliferate rapidly within human populations, even in the absence of direct contact with antibiotics. India's large consumption of raw and unpasteurized milk further amplifies this threat. While boiling milk kills most bacteria, many households fail to heat the milk adequately. Moreover, the belief that “fresh milk from local farms is healthier” encourages direct consumption without proper treatment. In such scenarios, resistant bacteria like *E. coli*, *Staphylococcus aureus*, and *Enterococcus* spp. can enter the human body alive and multiply in the digestive tract. Children, particularly those under five years of age, are highly vulnerable due to their developing immune systems and higher milk consumption rates. The public health sector also faces economic consequences due to AMR.

Treatment of resistant infections requires longer hospital stays, more expensive antibiotics, and advanced diagnostic tools. Many rural families, who consume raw milk out of tradition or affordability, may not have access to such medical facilities. As resistant infections

become harder to treat, the economic strain on households and the healthcare system grows exponentially, pushing more families into poverty.

Importantly, dairy farm workers and veterinarians face occupational exposure to resistant bacteria. Close contact with infected animals and contaminated milking equipment increases their risk of acquiring resistant infections. These individuals can subsequently transmit resistant bacteria to their family members or community, creating a silent but continuous cycle of AMR transmission. Thus, AMR must be viewed not simply as an agricultural issue but as a widespread public health crisis requiring urgent attention. The dairy sector stands at a critical intersection between animal and human health. Effective interventions—such as reducing antibiotic misuse, implementing strict withdrawal periods, improving milk handling practices, and promoting natural alternatives can prevent resistant bacteria from entering the food chain. Recognizing the public health implications of AMR is the first step in designing comprehensive strategies that safeguard both human and animal populations.

THE URGENT NEED FOR SAFE ALTERNATIVES TO ANTIBIOTICS

The alarming rise of antibiotic resistance in dairy farming has created an urgent necessity to rethink disease management strategies. For decades, antibiotics have been considered the “gold standard” for treating mastitis and other bacterial infections in dairy animals. However, heavy reliance on these drugs has led to a vicious cycle: the more antibiotics are used, the more resistant the pathogens become. This escalating resistance not only renders treatments ineffective but also jeopardizes milk safety and public health. The dairy sector can no longer depend on antibiotics as the primary means of maintaining udder health. One of the most compelling reasons for adopting alternatives to antibiotics is the rapid decline in antibiotic effectiveness. Many commonly used drugs, such as penicillin, oxytetracycline, tetracycline, enrofloxacin, and cephalixin, are now failing to cure mastitis cases that were once easily treatable. Repeated treatment failures frustrate farmers, prolong animal suffering, and reduce milk yield significantly. Chronic mastitis cases keep shedding bacteria into milk for months, contributing to a farm-wide reservoir of resistant organisms. Thus, reducing the use of antibiotics is not just desirable it is essential for breaking the cycle of resistance.

Another urgent factor is the issue of antibiotic residues in milk. When farmers do not follow recommended withdrawal periods after antibiotic treatment, residues remain in the milk and enter the consumer market. These residues have been detected in multiple studies across

India. Even low-level residues can trigger allergic reactions in sensitive individuals, especially children. More importantly, antibiotic residues create low-dose selective pressure on human gut bacteria, encouraging them to develop resistance. This slow but persistent exposure contributes significantly to the global AMR crisis. The increasing demand for “residue-free,” “organic,” or “natural” dairy products in urban markets further strengthens the case for antibiotic alternatives. Consumers are becoming more aware and cautious about what they consume. Milk cooperatives, dairy unions, and private companies are also pushing for safer milk production methods to maintain consumer trust and meet international standards. Export-quality dairy products must pass stringent residue tests, forcing the industry to shift towards safer disease management systems.

Furthermore, India’s dairy sector is **dominated** by smallholder farmers who manage 2–5 cows or buffaloes. These farmers are often not trained in judicious antibiotic use or do not have access to veterinary services. As a result, they may treat animals based on informal advice, leading to misuse. Providing these farmers with safe, practical, low-cost alternatives such as herbal therapies or NSAIDs reduces antibiotic misuse and improves animal welfare. These alternatives are easy to prepare, require minimal technical training, and do not compromise milk safety. There is also a growing international movement encouraging reduced antibiotic use in livestock. Many European countries have implemented strict antibiotic policies and promote alternatives like phytotherapy and immunomodulators. India, being the world’s largest milk producer, cannot remain behind. Global trade, food safety regulations, and consumer expectations demand that India modernize its dairy health management practices. Adoption of non-antibiotic alternatives aligns with national goals such as “One Health,” “Doubling Farmers’ Income,” and “Sustainable Livestock Development.”

Ultimately, the need for alternatives arises not merely from the dangers of antibiotic misuse but from the opportunity to build healthier, more sustainable dairy systems. Alternatives such as Ethno-Veterinary Medicine (EVM), NSAIDs, and antimicrobial peptides (AMPs) are not just replacements they represent a paradigm shift. These approaches honor traditional knowledge, incorporate modern science, and ensure milk safety without contributing to resistance. They empower farmers, protect consumers, and safeguard the long-term viability of India’s dairy industry.

ETHNO-VETERINARY MEDICINE (EVM): A RETURN TO SAFE, TRADITIONAL HEALING

Ethno-Veterinary Medicine (EVM) represents a powerful return to traditional, plant-based healing systems that have been practiced for centuries by livestock keepers across India. These healing traditions were once the primary method of managing cattle diseases, long before modern antibiotics were developed. In recent years, EVM has gained renewed attention due to the global concern surrounding antimicrobial resistance (AMR) and the increasing need for safe, residue-free milk production. Today, EVM stands at the crossroads of traditional wisdom and scientific validation, offering a holistic, sustainable solution to the challenges faced by the dairy sector. One of the core strengths of EVM lies in its accessibility and affordability. Most herbal ingredients used in EVM—such as turmeric, aloe vera, neem, garlic, tulsi, and red ginger—are readily available in rural households or local markets.

This allows smallholder farmers to prepare remedies quickly without depending on expensive pharmaceuticals or veterinary appointments. For millions of farmers who rely on dairy animals as their primary livelihood, EVM provides an immediate, practical, and low-cost method for managing diseases like mastitis, fever, diarrhea, wounds, and parasitic infections. TANUVAS has played an instrumental role in bringing EVM into mainstream animal healthcare. Since 2015, TANUVAS has organised certified training programmes on EVM, documented indigenous practices from local communities, and scientifically validated numerous herbal formulations for livestock. These efforts have significantly improved farmer trust and awareness, inspiring thousands of farmers across Tamil Nadu and neighboring states to adopt EVM practices. Scientific validation also ensures that EVM remedies are not merely traditional beliefs but are based on measurable antibacterial, anti-inflammatory, and immunomodulatory properties.

Many herbs used in EVM possess strong antimicrobial activity against common mastitis pathogens. For example, red ginger (*Zingiber officinale* var. *rubrum*) has demonstrated potent bactericidal effects against *Staphylococcus aureus*, *S. epidermidis*, and *S. agalactiae*, the primary organisms responsible for bovine mastitis. The active compounds—gingerols and shogaols—disrupt bacterial cell walls, inhibit protein synthesis, and reduce inflammation. Similarly, turmeric contains curcumin, a well-known natural antimicrobial and anti-inflammatory agent that supports faster healing of udder tissue. Another important benefit of EVM is its non-invasive nature. Unlike antibiotics, herbal treatments do not require injections or repeated veterinary

interventions. Remedies are typically administered orally, topically, or through herbal decoctions. This makes them easier for farmers to use, especially during emergencies. Moreover, since these remedies do not leave chemical residues, there is no milk withdrawal period, allowing farmers to continue milk sales without fear of contaminating the milk supply chain. EVM also contributes to improving milk quality. When antibiotics are used, they may temporarily reduce bacterial infection but also run the risk of leaving residues that lower milk acceptance at dairies. Herbal therapies, on the other hand, naturally enhance udder health, reduce somatic cell count (SCC), and support cleaner milk production. Studies conducted by TANUVAS and other research institutions have shown visible improvements in milk quality metrics when EVM is used consistently, especially in managing subclinical mastitis.

Beyond direct antimicrobial effects, many herbs in EVM exhibit strong immunomodulatory properties. This means they enhance the cow's natural immune response, helping the animal fight infection more effectively. Ingredients like tulsi, garlic, and ashwagandha stimulate macrophage activity, increase antibody production, and strengthen the overall immune system. A stronger immune system reduces the frequency and severity of infections, ultimately reducing the need for antibiotics altogether. EVM also promotes holistic animal well-being, addressing not just the symptoms but the root causes of disease. Poor udder hygiene, nutritional imbalance, stress, and environmental factors often contribute to mastitis and other infections. EVM treatments are frequently combined with improved animal management practices: clean bedding, proper milking hygiene, balanced nutrition, and stress reduction. This integrated approach aligns with One Health principles and ensures long-term animal productivity. The ecological benefits of EVM are equally important. Unlike antibiotics, herbal remedies do not contribute to environmental contamination. Antibiotics excreted in dung and urine can persist in soil and water for long periods, creating "hotspots" of resistance. Herbal compounds, however, are biodegradable and do not exert selective pressure on environmental bacteria. Thus, EVM not only protects animal and human health but also preserves ecosystem integrity.

Another key aspect is community empowerment. EVM knowledge is often shared through farmer-to-farmer networks, self-help groups, and KVK training programmes. This shared learning culture strengthens rural communities, reduces dependence on external inputs, and enhances local resilience. Women farmers, in particular, benefit greatly from EVM training

as they are closely involved in daily cattle care and milk production. In summary, Ethno-Veterinary Medicine offers a scientifically supported, farmer-friendly, and environmentally safe alternative to antibiotics in dairy farming. By integrating traditional wisdom with modern validation, EVM helps reduce antibiotic misuse, improves milk quality, lowers treatment cost, and enhances overall herd health. As AMR continues to rise globally, EVM stands out as a powerful tool that can reshape the future of sustainable milk production in India.

In conclusion, antibiotic resistance in dairy farming represents a silent but serious threat that requires immediate action. By embracing natural alternatives such as EVM, NSAIDs, and AMPs, and by strengthening regulatory frameworks and farmer education, India can lead the way in producing safer, residue-free, and sustainable milk. The shift towards antibiotic-free livestock health management is not just a scientific necessity but a moral responsibility—to protect our animals, our consumers, and our future.

References

- Acar, J. & Rostel, B. (2001). *Antimicrobial resistance: an overview*. *Revue Scientifique et Technique*, 20(3): 797–810.
- Alexa Oniciuc, E. A., Walsh, C. J., Coughlan, L. M., Awad, A., Simon, C. A., Ruiz, L., et al. (2020). *Dairy products and processing environments as reservoirs of antibiotic resistance and quorum-quenching determinants revealed through functional metagenomics*. *mSystems*, 5: e00723-19.
- Bhatt, V. D., Ahir, V. B., Koringa, P. G., Jakhesara, S. J., Rank, D. N., & Nauriyal, D. S. (2012). *Milk microbiome signatures of subclinical mastitis-affected cattle analysed by shotgun sequencing*. *Journal of Applied Microbiology*, 112(4): 639–650.
- Brahma, R., Mukherjee, R., Banerjee, S., et al. (2022). *Antibiotic resistance profiling of Staphylococcus aureus isolated from bovine mastitis milk*. *Veterinary World*, 15(5): 1245–1253.
- Call, D. R., Davis, M. A. & Sawant, A. A. (2008). *Antimicrobial resistance in beef and dairy cattle production*. *Animal Health Research Reviews*, 9: 159–167.
- Chandrasekaran, D., Rao, G. S., Nambi, A. P., et al. (2015). *Prevalence and antimicrobial susceptibility of mastitis pathogens in dairy cows*. *Indian Journal of Animal Sciences*, 85(2): 125–129.

- Claeys, W. L., Cardoen, S., Daube, G., et al. (2013). *Raw or heated cow milk consumption: review of risks and benefits*. Food Control, 31: 251–262.
- Dumford, D. & Skalweit, M. (2016). *Antimicrobial-resistant infections and challenges in clinical management*. Clinical Infectious Diseases, 62(4): 512–519.
- Freitag, C., Michael, G. B., Kadlec, K., et al. (2017). *Antimicrobial-resistant bacteria in agricultural livestock and food chains*. Journal of Dairy Science, 100(1): 561–570.
- Krishnamoorthy, P., Gnanaraj, P., Govindaraj, G., et al. (2017). *Antimicrobial susceptibility pattern of bovine mastitis pathogens in India: A meta-analysis*. International Journal of Veterinary Science, 6(3): 142–148.
- Lago, A., Godden, S., Bey, R., et al. (2011). *Non-antibiotic approaches for mild and moderate clinical mastitis in dairy cows*. Journal of Dairy Science, 94: 242–256.
- Mubarack, M. H., Dhanabalan, R., & Balasubramanian, V. (2012). *Antibiotic resistance in bovine mastitis pathogens*. Indian Veterinary Journal, 89(3): 54–57.
- Rubiola, S., Giannattasio, A., Chiesa, F., et al. (2020). *Bulk tank milk as a model for evaluation of microbiome and resistome using metagenomics*. Scientific Reports, 10: 1–13.
- Wang, G., Li, X. & Wang, Z. (2016). *APD3: The Antimicrobial Peptide Database as a tool for research and education*. Nucleic Acids Research, 44(D1): D1087–D1093.
- Zingiber officinale (Red Ginger) antibacterial studies – Multiple sources synthesized from peer-reviewed journals in phytotherapy and veterinary microbiology (2015–2023).

Volume: 05 Issue No: 12

IMPACT OF CLIMATE CHANGE ON INTEGRATED PEST MANAGEMENT (IPM): ADAPTING PEST CONTROL IN A WARMING WORLD

Article ID: AG-VO5-I12-77

Singam Sushmitha*

Department of Entomology, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India

*Corresponding Author Email ID: sushmithento96@gmail.com

Introduction

Climate change is reshaping agriculture across the globe. Rising temperatures, altered rainfall patterns, and increasing frequency of extreme weather events are affecting everything from planting seasons to crop yields. But one of the most subtle—and increasingly disruptive—consequences is the impact on **insect pests and the strategies used to manage them**.

As pests expand their ranges, reproduce faster, and appear in new seasons, traditional pest control methods are being challenged. In this evolving landscape, **Integrated Pest Management (IPM)** must adapt to stay effective, sustainable, and economically viable.

What is IPM and Why Does It Matter?

Integrated Pest Management (IPM) is a holistic approach to controlling pests that combines:

- **Biological controls** (natural predators, parasites)
- **Cultural practices** (crop rotation, sanitation)
- **Mechanical tools** (traps, barriers)
- **Chemical pesticides** (as a last resort)

The goal of IPM is to maintain pest populations **below economic thresholds**, with minimal harm to human health, beneficial organisms, and the environment.

As climate patterns shift, so do the ecological balances that IPM relies on—posing both **challenges and opportunities** for its effectiveness.

How Climate Change Affects Insect Pests

Insects are **ectothermic (cold-blooded)**, meaning their development, reproduction, and behavior are directly influenced by temperature and moisture.

Even small changes in climate can have big impacts:

1. Extended Growing Seasons

- Warmer temperatures allow pests to remain active for longer periods.
- More generations per year mean higher population densities.

Example: The **cotton bollworm (*Helicoverpa armigera*)** is now completing 4–5 generations annually in regions that previously saw only 2.

2. Range Expansion

- Warmer climates allow tropical or subtropical pests to move into new temperate zones.
- This leads to **emergence of invasive species** in previously unaffected areas.

Example: The **fall armyworm (*Spodoptera frugiperda*)**, native to the Americas, has now spread across Africa and Asia due to favorable conditions.

3. Altered Pest-Host Dynamics

- Changes in crop growth and phenology (timing of flowering, fruiting) can create mismatches or opportunities for pests.
- Stress-weakened crops are more vulnerable to insect attack.

4. Increased Resistance Pressure

- Frequent pest outbreaks lead to increased pesticide use.

This accelerates the development of **insecticide resistance**, undermining control efforts.

Implications for IPM: Challenges and Adaptation Needs

As climate change alters pest behavior, IPM strategies must evolve accordingly. Here are key areas where adaptation is essential:

➤ Monitoring and Forecasting

Traditional pest calendars are no longer reliable. Climate-induced changes in pest phenology require:

- **Real-time monitoring** using traps and sensors.
- **Predictive models** incorporating climate data.
- Use of **GIS and remote sensing** to map outbreaks and migration.

Example: In rice fields of Southeast Asia, predictive models are being developed to forecast outbreaks of the **brown planthopper**, whose population dynamics have shifted with rising temperatures.

➤ Biological Control Under Stress

Natural enemies—predators and parasitoids—are also impacted by climate change:

- **Asynchronous life cycles** between pests and their natural enemies can reduce biocontrol effectiveness.
- High temperatures may reduce survival or fecundity of parasitoids.

Adaptation strategy:

- Selection and release of **climate-resilient biocontrol agents**.
- Enhancing **agroecological diversity** to buffer ecological changes.

➤ **Cultural Control Practices**

Some traditional IPM tactics may become less effective or require modification:

- Crop rotation may be disrupted by erratic rainfall.
- Altered planting dates may not avoid **peak pest** periods anymore.
- New crop varieties might attract different pests.

Adaptation strategy:

- **Dynamic IPM plans** tailored to local climate projections.
- Collaboration with meteorological agencies for agri-climate advisories.

Climate-Smart Innovations in IPM

To stay ahead of pest dynamics, several innovations are emerging:

✓ **Climate-Resilient Biopesticides**

- Heat-tolerant strains of fungi like *Beauveria bassiana* are being developed.
- RNA-based biopesticides offer precise, environmentally safe control.

✓ **Digital Pest Monitoring**

- Smartphone apps, satellite tools, and AI-powered image recognition help farmers identify and respond to pest outbreaks quickly.

✓ **Genetically Modified Crops**

- Climate-adapted Bt crops are being researched to target specific pest species that emerge under warming scenarios.

✓ **Farmer Networks and Citizen Science**

- Community-based pest monitoring enables rapid response to new outbreaks.

The Role of Policy and Extension Services

To make IPM climate-resilient, policy and education must step up:

- **Government support** for biopesticide development and subsidies.

- Inclusion of **climate-risk assessments** in pest management programs.
- Strengthened **extension systems** to provide localized, up-to-date IPM guidance.
- Promotion of **climate-smart agriculture** (CSA) that integrates IPM, soil health, and water conservation.

Turning Challenges into Opportunities

While climate change disrupts pest management, it also presents opportunities to:

- Promote **diverse cropping systems** that are more pest-resilient.
- Build **stronger local food systems** less dependent on chemical inputs.
- Encourage **farmer-led innovation** and ecological knowledge sharing.

Ultimately, IPM must shift from being a static protocol to a **flexible, adaptive management system** grounded in real-time data, climate science, and ecological principles.

Conclusion: Rethinking IPM for a Warmer World

As the climate continues to change, pests will not wait. They will arrive earlier, stay longer, and multiply faster. In this new reality, the old models of pest control no longer suffice.

Integrated Pest Management must evolve—becoming more dynamic, data-driven, and climate-informed. By embracing innovation, strengthening research, and empowering farmers with knowledge, we can ensure that IPM remains a cornerstone of sustainable agriculture in the face of climate uncertainty.

A warming world demands cooler heads—and smarter pest control strategies.

Volume: 05 Issue No: 12

THE ROYAL SECRET OF THE HIVE: HOW HONEYBEES DETERMINE SEX

Article ID: AG-VO5-I12-78

***A. Madhumathi and D. Gigendhiran**

Assistant Professor in Genetics and Plant Breeding, School of Agricultural Sciences, Takshashila University, Villupuram, Tamil Nadu

Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore.

*Corresponding Author Email ID: madhuagri9196@gmail.com

Introduction

Sex determination is the process of sex differentiation that involves various genetic mechanisms to decide whether an individual develops as male or female. This process varies among species. Most animals are unisexual, whereas plants may be either unisexual or bisexual. Sex is identified with the help of sex characters that can be observed morphologically. These sex characters are expressed through chromosomes and genes. In some cases, environmental factors also play an important role in sex expression. Chromosomes are of two types: autosomes, which are identical in both males and females, and sex chromosomes (allosomes), which differ between males and females and contain the genes responsible for sex determination. Each unisexual diploid individual has two sex chromosomes and rest autosomes.

Genetics behind Sex Determination in Bees:

The sex of honeybees is controlled not just by fertilization but also by specific genetic mechanisms, particularly involving the complementary sex determiner (*csd*) gene. Here's how it works:

1. The *csd* Gene: The *csd* gene is the key genetic switch for sex determination in honeybees. A fertilized egg that is heterozygous at the *csd* locus (has two different alleles) develops into a female (worker or queen). An egg that is hemizygous (has only one allele, as in an unfertilized egg) becomes a male drone (Fig. 1).

2. Diploid Males: If a fertilized egg accidentally receives two identical alleles of the *csd* gene, it becomes a diploid male. Diploid males are unviable in the colony and are typically detected and removed by worker bees. This ensures colony health.

3. Role of Ploidy

Haploid (unfertilized) eggs → male drones

Diploid (fertilized) eggs → females

This haplodiploid system combined with the *csd* gene ensures precise control of sex ratios in the colony.

4. Evolutionary Significance: Haplodiploidy and the *csd* gene contribute to the high relatedness among worker bees. Workers share more genes with their sisters than they would with their own offspring, promoting altruistic behaviors that maintain the colony.

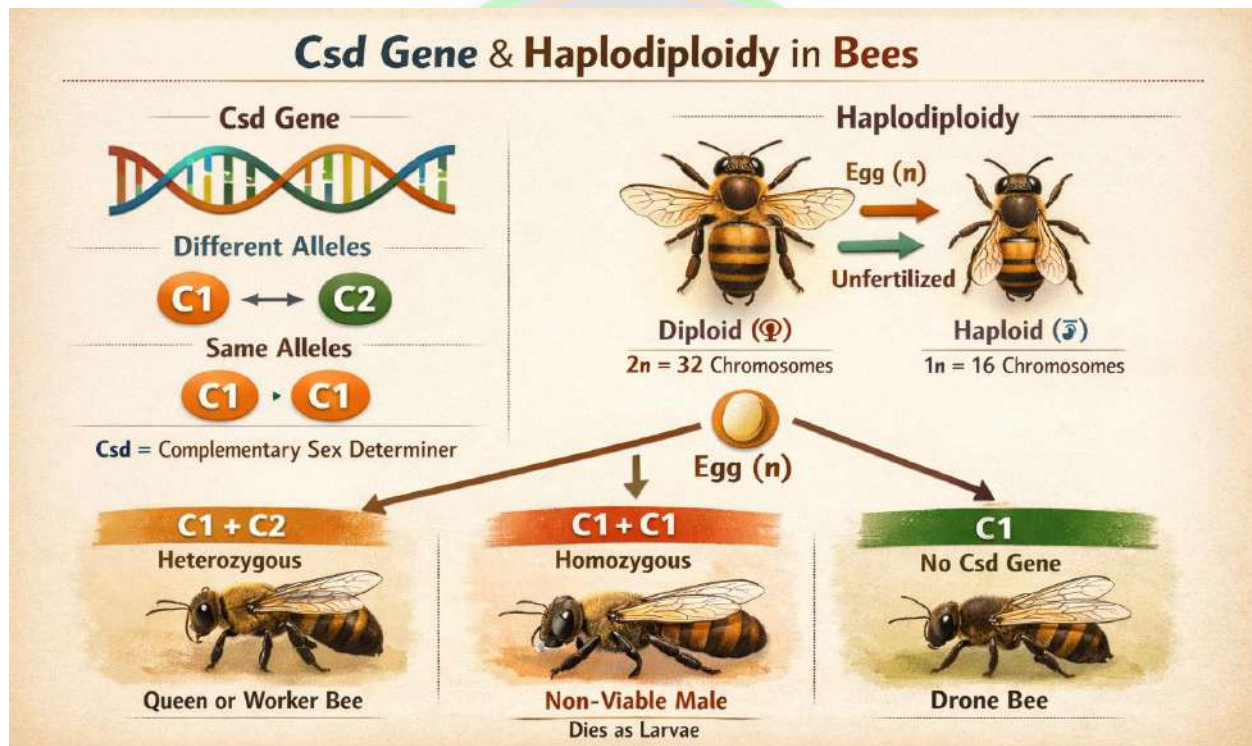


Fig. 1: Sex determination in honey bee

Haplodiploidy: The Core Rule in Bee Sex Determination

Inside a honeybee colony, sex determination follows a precise biological system that plays a crucial role in shaping the entire social structure of the colony. Haplodiploidy is the fundamental mechanism by which sex is determined in honeybees. In this system, the sex of an individual depends on whether the egg is fertilized. Fertilized eggs develop into diploid females, which may

become workers or queens, while unfertilized eggs develop into haploid males known as drones. This unique form of sex determination plays a key role in the organization, behavior, and social structure of the honeybee colony. This system is fundamentally different from the method of sex determination seen in humans and most other animals, where both males and females develop from fertilized eggs with different sex chromosomes.

The Queen's Remarkable Control:

The queen honeybee plays a central and highly strategic role in the hive. After mating with several drones during her nuptial flight, she stores the collected sperm in a specialized organ called the spermatheca, where it can remain viable for several years. When laying eggs, the queen exercises remarkable control over sex determination by deciding whether or not to release sperm from the spermatheca.

- If she releases sperm, the egg is fertilized and develops into a female, which can become either a worker or a queen depending on nutrition and care.
- If she does not release sperm, the egg remains unfertilized and develops into a male drone, whose primary role is to mate with queens from other colonies.

This ability allows the queen to actively manage the colony's population and social structure. She can increase the number of workers to support growth and maintenance of the hive or produce more drones when it is time for mating, ensuring the colony's survival and genetic diversity. This precise control highlights the queen's central role in the complex, highly organized society of honeybees.

Conclusion

The process of sex determination in honeybees is a remarkable combination of genetic, developmental, and behavioral mechanisms that ensures the survival and efficiency of the colony. Through the haplodiploid system, fertilized eggs develop into females while unfertilized eggs produce males, and the *csd* gene acts as a precise genetic switch to regulate this process. The queen honeybee exerts exceptional control over the colony's sex ratio by selectively fertilizing eggs, allowing her to balance the production of workers and drones according to the hive's needs. This intricate system not only maintains colony health by preventing the survival of diploid males but also promotes cooperation and altruistic behavior among workers. Overall, the genetic and biological mechanisms of sex determination in honeybees reveal the sophistication of their social organization and highlight the essential role of the queen in sustaining the hive.

BEYOND ANTIBIOTICS: THE PROBIOTIC REVOLUTION IN SUSTAINABLE AQUACULTURE

Article ID: AG-VO5-I12-79

Avadhutha Nikhil^{1*}, P Vamshi Krishna Reddy¹, Anurag Kumar², Vinjam Akshitha³¹TNJFU, Dr. MGR Fisheries College and Research Institute, Ponneri, Tamil Nadu²College of fisheries (ANDUA and T), Kumarganj, Ayodhya (U.P), India³College of fisheries science, Pebbair, Telangana, India*Corresponding Author Email ID: nikhil.avadhutha1342@gmail.com

Abstract

Global aquaculture is expanding rapidly; however, its sustainability is constrained by disease outbreaks, environmental concerns and the overuse of antibiotics. Probiotics, which are live microorganisms administered through feed or water and provide an eco-friendly method, have emerged to improve fish and shellfish health. They greatly enhance growth, feed efficiency, survival and stress tolerance in many species by improving gut health, immunity, digestion and water quality. Along with these advantages, some challenges such as strain selection, viability, dosage, method application and regulatory gaps limit large-scale implementation. To address these challenges and promote antibiotic-free, sustainable aquaculture, synbiotic-based combinations offer effective solutions.

Keywords: Probiotics; Sustainable aquaculture; Synbiotic; Antibiotic; Feed efficiency.

1. Introduction

Aquaculture is one of the fastest-growing food sectors in the world, but diseases outbreaks, environmental degradation, unsustainable use of antibiotics and chemotherapeutics are limiting its growth. Among these, disease outbreaks are one of the major issues affecting aquaculture production, impacting social and economic development in many nations (Tuan *et al.*, 2013). In this condition, probiotics which contains beneficial live microorganisms given through feed or administered into the aquatic environment have emerged as an environmentally responsible approach to disease control in fish and shellfish farming. Probiotics have been used

extensively in aquaculture to improve water quality, enhance immunity, control diseases, provide nutritional and enzymatic support for the host's digestion (Qi *et al.*, 2009).

2. Probiotics in Aquaculture

Probiotics are live microbial supplements that provide health benefits when given in adequate amounts, they function in multiple synergistic mechanisms. These mechanisms include competitive suppression of pathogens, production of antimicrobial metabolites, modulation of immune responses, enhancement of nutrient assimilation and stabilization of microbial communities in the gastrointestinal tract and the surrounding water. Their multiple modes of action not only decrease the chances of pathogen resistance but also complies with international regulatory frameworks that encourage sustainable and antibiotic-free aquaculture. Several studies reveal an increasing number of such "good bacteria" that they lead to better growth, higher digestive efficiency, stronger immune system and the improvement of pond water and soil conditions

Probiotics are used as therapeutic, a preventative measure and growth supplements in animal husbandry and human health. Lactic acid bacteria (LAB) are known to be found in the intestines of healthy fish and have generally been used and studied extensively for human and terrestrial animal purposes (Pandiyani *et al.*, 2013).

3. Probiotic Organisms Used in Aquaculture

Globally, a wide variety of Gram-positive bacteria are used frequently as probiotics. Members of the *Bacillus* genera that form endospores have a wide range of applications. *Bacillus subtilis* is commonly used in aquaculture (Hai, N. V. 2015)..

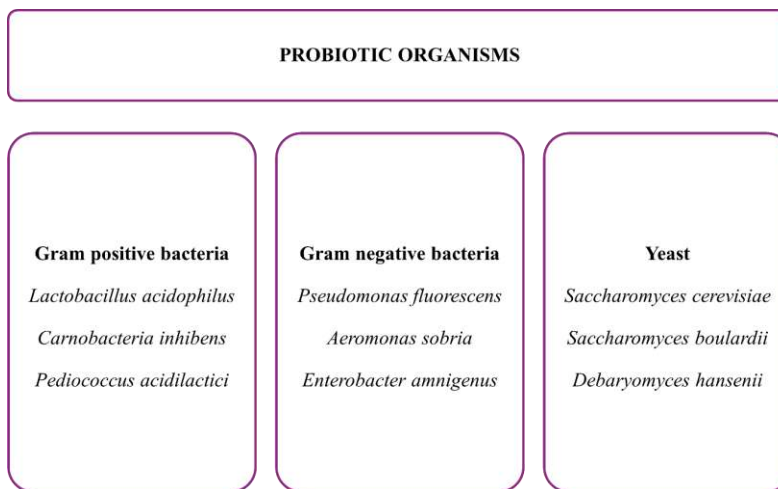


Fig.1: Probiotic organisms (Hoseinifar *et al.*, 2018).

As a result, probiotic treatments with strains such as *Lactobacillus*, *Bacillus*, *Pediococcus*, *Enterococcus* and *Shewanella* have been very effective in a variety of species like carp, tilapia, trout and shrimp. However, even with these benefits like faster growth, better feed use, higher survival during disease outbreaks and improved water quality, a few challenges still remain

4. Mechanisms of Probiotic Action in Aquaculture

Probiotics provide their beneficial effects through several connected biological processes that improve the host's health and support a stable environment.

4.1 Competitive Suppression of Pathogens

Probiotics promote competitive suppression by binding to the intestinal epithelium and occupying binding sites, which prevents harmful pathogens from attaching and as a result, pathogens cannot colonize.

4.2 Production of Antimicrobial Compounds

probiotics protect the host by releasing antimicrobial compounds such as bacteriocins and organic acids. These substances lower the gut pH, creating conditions that are unfavorable for harmful bacteria like *Vibrio*, *Aeromonas* and *Streptococcus* to grow.

4.3 Immunomodulation

Probiotic strains influence the immune system as they interact with both the innate and adaptive immune responses by controlling cytokine production, stimulating phagocytic activity and raising the immune cells activity.

4.4 Enhancement of Digestion and Nutrient Absorption

Many probiotics release digestive enzymes or enhance enzyme production in the host, leading to better digestion and nutrient absorption.

5. Types of Probiotics Used in Aquaculture

Probiotics used in aquaculture can be broadly classified into four main types based on their form and method of preparation: viable (live), non-viable, freeze-dried and fermentation-based probiotics. Each type differs in stability, mode of action and practical application.

6. Advantages of Probiotics in Aquaculture

Probiotics play an important role in aquaculture by maintaining a healthy gut microbiota, enhancing the immune system and improving nutrient absorption and utilization in fish.

6.1 Health Improvement and Disease Resistance

Probiotics enhance fish health by controlling harmful microbes, strengthening immune responses, increasing resistance to oxidative stress and maintaining water quality through the breakdown of organic waste and stabilization of microbial communities, maintaining low levels of ammonia.

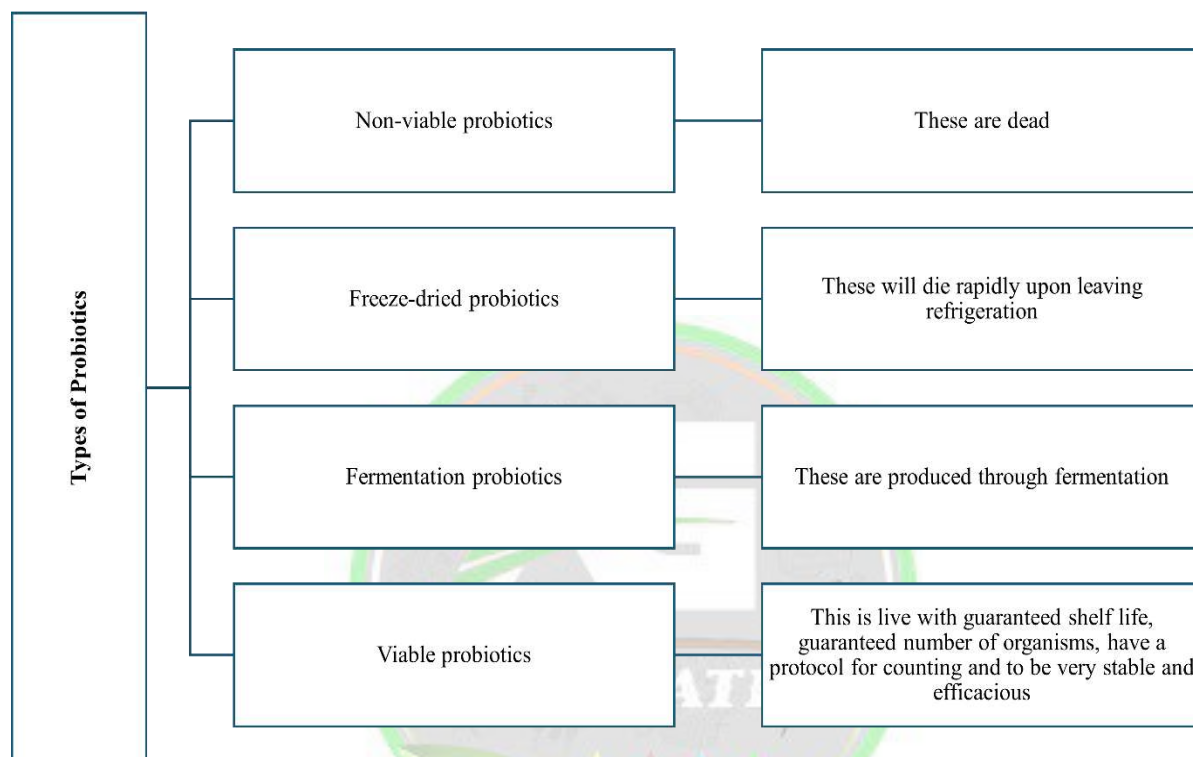


Fig.2: Different types of probiotics (Rao, 2010)

6.2 Growth Promotion and Feed Efficiency

Probiotics promote growth by producing digestive enzymes such as amylases, proteases, and lipases, which improve nutrient digestion, absorption, and feed conversion. This leads to higher weight gain, better body protein and lipid content, and increased growth rates in species like Nile tilapia and rohu, making energy use more efficient.

6.3 Survival Rate and Stress Tolerance

Probiotics improve fish survival by limiting harmful bacteria, enhancing stress tolerance in larval conditions and enhancing immunity.

6.4 Water Quality Improvement

The regular use of probiotics helps maintain healthy and stable conditions in ponds, thereby reducing mortality caused by infections and environmental stress.

7. Challenges and Future Directions

Application of probiotics in aquaculture improves growth, digestion, immunity and survival of cultured fish and shellfish; however, several challenges still limit their large-scale and consistent use. Differences in probiotic efficiency among studies have been attributed to incomplete strain characterization, host-specific adaptation, inconsistent dosing and delivery methods affected by factors such as salinity and temperature. Biosafety concerns, such as the transfer of antibiotic resistance, changes to the natural microbiota and the risk of opportunistic infections, make it necessary to conduct careful genomic checks and long-term ecological studies before using probiotics in aquaculture. Regulatory issues also limit commercialisation and quality control requirements for aquatic use.

Future research is focusing on **probiogenomics** to select effective, species-specific probiotic strains. Simultaneously, techniques like microencapsulation are being applied to ensure that probiotics remain stable and functional in RAS and biofloc systems. There is also significant potential in combining probiotics with synbiotics, vaccines and microbiome engineering to further enhance animal health. To make probiotics accessible for small-scale farmers, it is essential to address production costs and implement effective policy incentives. Collaboration among scientists, industry stakeholders and regulators can bridge these gaps and position probiotics as a key component of sustainable aquaculture amid rising global demand.

Conclusion

Probiotics are developing as an essential tool for sustainable aquaculture and generally regarded as safe and more environmentally friendly alternative to antibiotics and cost-effective solutions to improve production without affecting the environment. They can be used in a wide variety of farming systems, including ponds, cages, biofloc and RAS. Probiotics strengthen the immune system and lower disease outbreaks by inhibiting the growth of harmful microbes. They enhance the growth and survival of fish by improving digestion, nutrient absorption and gut health. However, sustained advancement is dependent on selecting the right strains and administering proper doses. Overall, when used effectively, probiotics serve as an eco-friendly and efficient tool that reduces chemical and antibiotic use, thereby promoting the development of a more resilient and sustainable aquaculture sector.

References

- Hai, N. V. (2015). The use of probiotics in aquaculture. *Journal of applied microbiology*, 119(4), 917-935.
- Hoseinifar, S. H., Sun, Y. Z., Wang, A., and Zhou, Z. (2018). Probiotics as means of diseases control in aquaculture, a review of current knowledge and future perspectives. *Frontiers in microbiology*, 9, 2429.
- Pandiyan, P., Balaraman, D., Thirunavukkarasu, R., George, E. G. J., Subaramaniyan, K., Manikkam, S. and Sadayappan, B. (2013). Probiotics in aquaculture. *Drug invention today*, 5(1), 55-59.
- Qi, Z.Z., X.H. Zhang, N. Boon and P. Bossier. (2009). Probiotics in aquaculture of China- Current state, problems and prospect. *Aquaculture*, 290, 15-21.
- Rao, A. V. (2010). Bioremediation–The Advanced Biotechnology Process to Restore the Health of Aquaculture Pond Ecosystem.
- Tuan, T. N., Duc, P. M. and Hatai, K. (2013). Overview of the use of probiotics in aquaculture. *International Journal of Research in Fisheries and Aquaculture*, 3(3), 89-97.



PROSPECTS OF SPINE GOURD (*Momordica dioica*) CULTIVATION IN NAGAPPATINAM DISTRICT

Article ID: AG-VO5-I12-80

¹Athithy Yoganathan, ¹K. Abitha, ¹T. Deepika Ranjani, ¹NR. Deva Dharsini, ¹S. Divya,¹V. Gopika, ¹R. Vasitha, ²G Ravi, ³PR. Kamalkumaran and ⁴*A. Anuratha¹UG Students, ²Nodal Officer, ³Assoc. Professor (Horticulture) and ⁴Assoc. Professor (SS & AC),

Agricultural College and Research Institute, Keezhvelur, Nagapattinam, Tamil Nadu, India

*Corresponding Author Email ID: anuratha.a@tnau.ac.in

Abstract

Spine gourd (*Momordica dioica*), locally known as “Pazhupagal” is an underutilized, but nutritionally rich vegetable crop cultivated in various parts of India. It is valued especially for its anti-diabetic and antioxidant effects. In Nagapattinam, the spine gourd cultivation is gaining importance as consumers demand for a healthy and nutritive vegetable. This article highlights the importance of survey and documentation about cultivation of spine gourd in Nagapattinam district of Tamil Nadu, India. The documentation includes growth habit, germination studies, biometric characters, traditional uses, nutritional value and market potential.

Keywords: Spine gourd, Nagapattinam, Biometric characters, Nutritional value, Market potential

Introduction

Spine gourd (*Momordica dioica* Roxb.) is a perennial, dioecious climber of the family Cucurbitaceae, cultivated mainly during the monsoon season in tropical and subtropical regions of India, Nepal, and Southeast Asia. The small, spiny fruits are nutritionally rich, providing vitamins A and C, iron, dietary fiber, and antioxidants, and are valued for their anti-diabetic, digestive, and anti-inflammatory properties. The crop thrives in warm, humid climates with temperatures of 25–30°C and grows best in well-drained sandy loam to loamy soils with a pH of 6.0–7.0. Propagation is primarily through underground tubers, although seeds and tissue culture

methods are also used. Planting coincides with the onset of the monsoon (June–July), and vines require staking or trellis systems for proper growth. Balanced nutrient application using FYM and chemical fertilizers, along with adequate spacing and irrigation, is essential for optimal yield. Due to its dioecious nature, maintaining an appropriate male-to-female plant ratio is critical for effective pollination. Major pests and diseases include fruit flies, aphids, powdery mildew, and mosaic viruses. Harvesting begins 3–4 months after planting, with an average yield of 6–10 t/ha. Owing to its high market price and relatively low input requirement, spine gourd offers a profitable cultivation option for small and marginal farmers.

Seed Germination Studies

Spine gourd exhibits a low seed germination rate (20–30%), primarily due to hard seed coats and physiological dormancy (Sirohi *et al.*, 2005). The hard, water-impermeable seed coat restricts moisture and gas exchange, while physiological dormancy requires specific environmental cues for germination. Techniques such as seed soaking, scarification, and seed-coat removal are effective in overcoming this hard seededness.

Mechanical scarification followed by soaking seeds in Gibberellic acid (GA_3 @ 200–500 ppm) significantly enhances germination and seedling vigor (Sharma & Dhankhar, 2008). Similarly, seed-coat removal combined with 24–48 hrs. of water soaking promote faster and more uniform germination (Singh *et al.*, 2010). Presoaking seeds in GA_3 @ 250 ppm for 24 hours has shown to increase germination by up to 60 per cent under nursery conditions, as GA_3 helps break dormancy by stimulating starch hydrolysis and energizing embryo growth (Raghavendra *et al.*, 2012). Additionally, treatments with potassium nitrate (KNO_3) and thiourea have demonstrated significant improvements in seedling emergence compared to untreated seeds, indicating that osmotic regulation and metabolic activation play essential roles in overcoming dormancy in *Momordica dioica* (Kumar *et al.*, 2016).

Vegetative Propagation Techniques

Farmers in the Nagapattinam district have reported the practice of using tubers as a vegetative propagule for the cultivation of spine gourd (*Momordica dioica*). Tubers retained from the previous crop cycle are segregated based on sex, and the selected male and female tubers are planted in predetermined proportions during the subsequent season. This approach enables growers to effectively maintain an optimum sex ratio, thereby overcoming the major limitation associated with seed propagation, particularly the low and unpredictable germination

rate and the difficulty in ensuring an appropriate male–female balance. In addition to tuber-based propagation, several other methods—such as stem cuttings, micropropagation through tissue culture techniques—are being employed to achieve higher multiplication rates, that ensure genetic uniformity, and support large-scale planting material production.

Biometric Characters

Fifteen-day-old seedlings of the local spine gourd (*Momordica dioica*) variety were collected from farmers in the Vedaranyam block, specifically from the villages of Katharipulam, Kuravapulam, and Sembodai. The collected seedlings were subsequently evaluated, and their biometric parameters were systematically observed and recorded for further analysis.

Table 1. Biometric characters of spine gourd plant

Characters	Days after planting									
	14	21	28	35	42	49	56	63	70	77
Vine length (cm)	13	72	113	155	164	186	194	202	214	220
No. of branches	3	4	4	4	5	5	5	5	5	5
Internode length (cm)	3	4.5	4.5	6	6	7	7	8	9	10
No. of leaves	14	21	27	38	40	56	67	73	84	93
Leaf length (cm)	4	4.5	4.3	4.8	6	6.5	6.6	6.8	7	7
Leaf width (cm)	3.5	3.5	4	4	5	6	6	7	8	8.5
Leaf area (cm ²)	15	16.5	17	19	30	39	39.6	47.6	56	59.5

Nutritional Value

Table 2. Nutritional composition of fruits of *Momordica dioica* (per 100 g edible fruit on dry weight basis) (Jitendra Kumar Tiwari *et al.*,2022)

Parameter	Nutrient Composition	Parameter	Nutrient Composition
Crude Protein (g)	19.38	Calcium (mg)	33.00
Crude lipid (g)	4.70	Phosphorus (mg)	42.00
Carbohydrates (g)	47.92	Iron (mg)	4.60
Crude fibre (g)	21.30	Riboflavin (mg)	0.18
Ash (g)	6.70	Thiamin (mg)	0.05
Calorific value (kcal)	311.50		

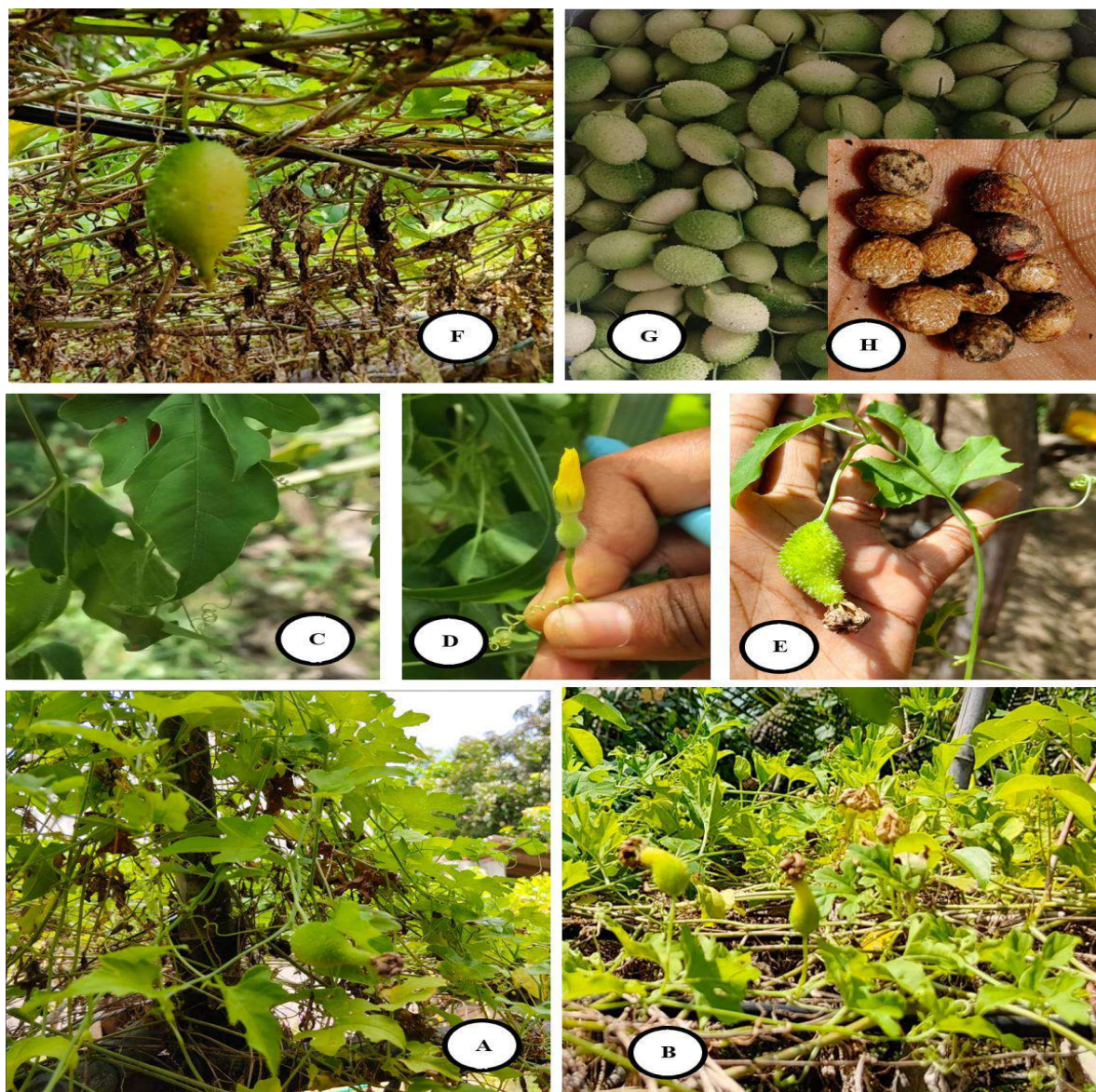


Fig. 1. Spiny Gourd (*Momordica dioica*) local cultivar of Nagapattinam. A. Plant trailing on pole. B. Plant trailing on trellis. C. Leaf, D. Female flower, E. Immature fruit, F. Matured fruit, G. Harvested fruit and H. Seeds.

Traditional Uses

Spine gourd (*Momordica dioica*) is widely consumed for its nutritional value and recognized for its antidiabetic properties, owing to its richness in dietary fiber, antioxidants, and bioactive compounds. In coastal regions, the fruit is traditionally cooked along with prawns, providing a nutritionally balanced dish that combines plant- and animal-based proteins, minerals, and essential micronutrients. Among vegetarian communities, spine gourd is commonly prepared by sautéing or frying chopped fruits with onions, garlic, and chilli powder, resulting in a simple yet nutrient-dense dish that retains much of the vegetable's therapeutic potential.

Market Potential

The market potential of spine gourd in Nagapattinam district is considerably high, owing to its nutritional richness and increasing consumer preference for health-promoting vegetables. In the contemporary context of rising awareness regarding diet-based health management, spine gourd offers substantial scope for commercialization due to its antidiabetic properties, antioxidant content, and overall nutritional value. From a post-harvest perspective, spine gourd is advantageous as it is relatively non-perishable, easy to handle, and requires minimal packaging and storage facilities. Being a tropical vegetable, it does not necessitate refrigeration or cold storage, thereby reducing the cost of transportation and enabling efficient supply chain management. Furthermore, the crop is suitable for inter-regional trade and export, both in fresh and processed (canned) forms, as it withstands transportation without significant quality deterioration. In Nagapattinam, consumer awareness and traditional culinary use of spine gourd are already well established. With increased awareness and promotional efforts in other regions, the market reach and commercial prospects of spine gourd could expand considerably, contributing to enhanced farmer income and diversification of vegetable markets.

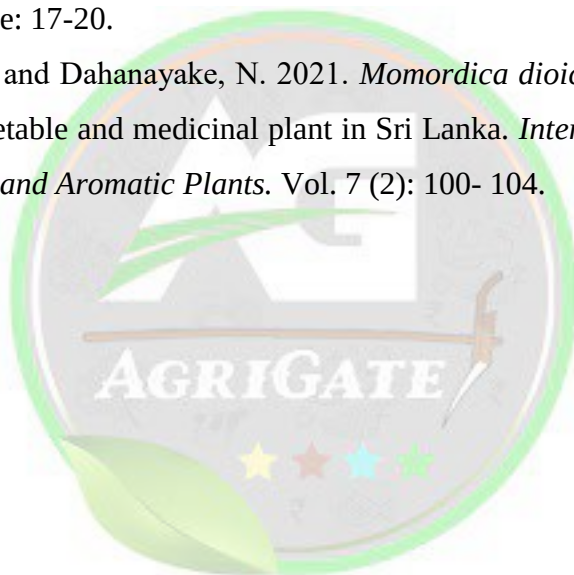
Conclusion

Spine gourd is a promising crop that requires relatively simple cultivation practices. Its major production constraints are the need to maintain an appropriate male-to-female plant ratio and the presence of seed dormancy, which affects germination. If these issues are addressed, the crop offers high market potential due to its notable nutritional and health benefits.

References

- Anjana, M., Swathi, V., Ramya, Sai A., Divya, N and Sunisha, Y. 2020. A Review on *Momordica dioica* Fruits. J. Adv. Plant Sci., 3: 101.
- Basumatara P, Bora GC, Kalita UC, Saikia L and Deka NC. *Variability and correlation studies in spine gourd (Momordica dioica Roxb.)*. Journal of Agriculture and Food Science. 2014 :77-81
- Jha, D.K., Koneri, R. and Samaddar, S. 2017. Potential Bio-Resources of *Momordica dioica Roxb*: A Review. Int. J. Pharm. Sci. Rev. Res., 45(2): 203-209
- Panchbhai DM, Shirsat L and Jogdane NK. Effect of GA₃ and chemicals on germination, growth and yield of Spine gourd (*Momordica dioica Roxb.*). *The Orissa Journal of Horticulture*. 2005; 33(1):61-64.

- Ponnusamy, J. and Balusamy, A. 2018. Spine gourd: An underutilized cucurbitaceous vegetable. Kerala Karshakan, e-journal (December):45-47.
- Rakh MS, ChaudhariSR. 2010. Literature survey of plant *Momordica dioica* Roxb. Wild. An update. Int. J Pharmacol Res Develop. 2010;1-8
- Talukdar, S.N. and Hossain, M.N. 2014. Phytochemical, Phyto-therapeutical and Pharmacological Study of *Momordica dioica*. Hindawi Publishing Corporation. Evidence-Based Complementary and Alternative Medicine Volume, Article ID 806082, 11 pages.
- Tiwari, J.K., Ameen, G., Sandilya, V.K., Kumar, S and Kaushik, S.K. 2022. Cultivation practices of an underutilized, yet wholesome and remunerative vegetable: Spine gourd. Indian Horticulture: 17-20.
- Weerasinghe, M.G.W.K. and Dahanayake, N. 2021. *Momordica dioica* Roxb (Spine Gourd) An underutilized vegetable and medicinal plant in Sri Lanka. *International Journal of Minor Fruits, Medicinal and Aromatic Plants*. Vol. 7 (2): 100- 104.



ROLE OF BIOCONTROL AGENTS IN ORGANIC FARMING

Article ID: AG-VO5-I12-81

Balaji M^{1*}, Dinesh G² and M P Kavitha³

^{1,2} B.Sc. (Hons.) Horticulture, Horticultural College & Research Institute (TNAU),
Periyakulam, Theni, Tamil Nadu - 625 604.

³Associate Professor, Department of Agronomy, Agricultural Research Station,
Tamil Nadu Agricultural University, Vaigai Dam, Theni, Tamil Nadu- 625 562.

*Corresponding Author Email ID: imbalajimmvb2004@gmail.com

Abstract

Organic farming emphasizes harmony between production and nature by avoiding synthetic chemicals and fostering ecological balance. However, pest, disease, and weed infestations continue to threaten productivity, often leading to substantial crop losses. Biological control offers a sustainable and eco-friendly alternative to chemical pesticides by using living organisms such as beneficial insects, bacteria, fungi, viruses, and nematodes to suppress harmful pests and pathogens. Predators like ladybird beetles, parasitoids such as *Trichogramma* wasps, and microbial agents including *Beauveria bassiana* and *Trichoderma* species are key contributors to natural pest regulation. Similarly, weed-suppressing insects and plant-pathogenic fungi help manage invasive species without disrupting soil health. Successful biocontrol agents are characterized by ecological compatibility, host specificity, adaptability, and ease of mass production. Integrating these agents into organic systems not only enhances crop health and yield but also promotes long-term sustainability. By reducing dependence on synthetic inputs, biocontrol practices empower farmers to produce safer, high-quality food while preserving biodiversity for future generations.

Key words: Organic farming, Biocontrol agents, Beneficial insects, sustainable agriculture

Introduction

Organic farming promotes a holistic production approach that minimizes synthetic input

use, aiming to preserve ecological balance and biodiversity. In crop production, farmers face significant challenges from weeds, insect pests & diseases. On average, there is 33% crop loss due to weeds, 26% crop loss due to plant diseases & 20% crop loss due to insect pests, controlling them is more difficult in organic farming compared to conventional/regular farming, where the synthetic inputs (pesticides like insecticides, herbicides& fungicides) are prohibited from usage. This highlights the importance of biocontrol agents in helping organic farmers protect their crops from pests and diseases. We will explore the types, significance, and application of biocontrol agents in organic farming.

Biocontrol agents

Biocontrol or Biological control is a method of controlling pests such as insects, mites, weeds & plant diseases through the use of other beneficial living organisms. It relies on natural mechanisms like predation, parasitism, herbivory, often requiring active human management. Biocontrol agents are living organisms, including parasitoids, predators, weed killers, antagonistic organisms like fungi, bacteria & viruses.



Why Biocontrol agents?

In organic farming, the use of chemical pesticides is prohibited. Hence the way to control insect pests, diseases and weeds in organic farming is either by cultural method or biological control method. Using cultural practices alone is insufficient to manage these issues, making biocontrol agents the best alternative for organic farming.

Biocontrol agents for Insect pests

Organism	Type of the agent	Common name of the agent	Scientific name/ commercial name of the agent	Insect controlled
Insect	Predators	Ladybird beetle/ coccinellid beetles	<i>Cryptolaemus montrouzieri</i>	Soft bodied insects like aphids

		Green lacewing (aphid lion)		<i>Chrysoperla carnea</i>	Aphids & small pests
		Praying mantis		<i>Mantis religiosa</i>	Grasshoppers, flies, bees,
		Ground beetles		<i>Poecilus halcites</i>	Soil insect pests
	Parasitoids	Egg	Trichogramma wasps	<i>Trichogramma spp.</i>	Lepidopteran pests
		Egg-larval	Blackburni parasitic wasp	<i>Chelonus blackburni</i>	Potato & cotton pests
		Larval	Cotesia wasp Braconid wasps	<i>Cotesia spp.</i> <i>Bracon brevicornis</i>	Lepidopteran borers & leaf feeders
		Pupal	Brachymeria	<i>Brachymeria spp.</i> <i>Trichospilus pupivora</i>	coconut black headed caterpillar
		Adult	Sugarcane pyrilla parasitoid	<i>Epiricania melenaleuca</i>	Sugarcane leaf hopper
Antagonistic microbes	Fungi	White halo fungus		<i>Verticillium lecanii</i>	Scale insects & other homopterans
		White muscardine fungus		<i>Beauveria bassiana</i>	Codling moth DBM, berry borer, Thrips & whitefly
		Green muscardine fungus		<i>Metarrhizium anisopliae</i>	Rhinoceros beetles, termites, leaf hoppers
		Riley's fungus		<i>Nomuraea rileyi</i>	Lepidopteran pests
	Bacteria	Entomopathogenic bacteria		<i>Bacillus thuringiensis</i>	Lepidopteran larva & grubs of coleoptera
	Virus	Nuclear polyhedrosis virus		SINPV, HaNPV	<i>Spodoptera</i> , <i>Helicoverpa</i> larva
		Granulovirus		Virosoft CP4	Apple codling moth

		Nudivirus	OrNV	Rhinoceros beetle
	Nematodes	Entomopathogenic nematodes	<i>Steinernema</i> , <i>Heterohabditis</i>	Grubs, weevils & cutworms
	Protozoa	Entomopathogenic protozoans	<i>Nosema locustae</i> , <i>Farinosystis triboli</i>	Grass hoppers Red flour beetle

Biocontrol agents for disease causing pathogens

Type of the agent	Name of the agent	Crop	Plant pathogens controlled
Fungal antagonist	<i>Trichoderma asperellum</i>	Onion	<i>Sclerotium cepivorum</i>
	<i>Trichoderma asperellum</i> T8a	Mango	<i>Colletotrichum gloeosporioides</i>
	<i>Trichoderma asperellum</i>	Beans	<i>Sclerotinia sclerotiorum</i>
	<i>Trichoderma hamatum</i>	Cabbage	<i>Sclerotinia sclerotiorum</i>
	<i>Trichoderma harzianum</i>	-	Root rot diseases like <i>Pythium</i> & <i>Fusarium</i>
	<i>Trichoderma virens</i>	-	Soil borne pathogens like <i>Rhizoctonia</i> & <i>Pythium</i>
	<i>Fusarium osysporum</i> (non-pathogenic strains)	-	Various fungal pathogens
Bacterial antagonist	<i>Bacillus thuringiensis</i>	Cabbage	<i>Sclerotinia sclerotiorum</i>
	<i>Bacillus subtilis</i> ATCC6633	Wheat & maize	<i>Fusarium graminearum</i> & <i>Fusarium verticillioides</i>
	<i>Bacillus velezensis</i> DMW1	Tomato	<i>Ralstonia solanacearum</i>
	<i>Bacillus amyloliquefaciens</i> FZB42	Tomato	<i>Sclerotinia sclerotiorum</i>
	<i>Bacillus licheniformis</i> BL06	Pepper	<i>Phytophthora capsici</i>
	<i>Bacillus megaterium</i>	Citrus	Blue mould
	<i>Streptomyces</i> sp. AN090126	Tomato	<i>Ralstonia solanacearum</i> & <i>Xanthomonas euvesicatoria</i>

	<i>Pseudomonas fluorescens</i>	-	<i>Pythium</i>
	<i>Pseudomonas protegens</i> Pf-5	Maize	<i>Pantoea ananatis</i>
	<i>Pseudomonas putida</i>	Rice	<i>Magnaporthe oryzae</i>
	<i>Agrobacterium radiobacter</i> K84	Rose family	Crown gall disease- <i>Agrobacterium tumefaciens</i>

Biocontrol agents for weeds

Type of the agent	Weed killing agent		Weeds controlled	
	Common name	Scientific name	Common name	Scientific name
Weed killers (Insects)	Cochineal insect	<i>Dactylopius tomentosus</i>	Prickly pear	<i>Opuntia dillenii</i>
	Moth borer	<i>Cactoblastis cactorum</i>		
	Mexican beetle	<i>Zygogramma bicolorata</i>	Parthenium	<i>Parthenium hysterophorus</i>
	Coccid/ scale	<i>Orthezia insginis</i>	Lantana	<i>Lantana camara</i>
	Calotropis butterfly	<i>Dannaus chrysippus</i>	Calotropis	<i>Calotropis gigantea</i>
	AK grasshopper	<i>Poecilocus pictus</i>		
	Weevil	<i>Neochetina eichornia</i>	Water hyacinth	<i>Eichhornia crassipes</i>
	Cuscuta fly	<i>Melanagromyza cuscuteae</i>	Dodder	<i>Cuscuta spp.</i>
Myco-herbicides (plant pathogens)	Fungal rust	<i>Puccinia chondrilina</i>	Skeleton weed	<i>Chondrilla juncea</i>
	Collego	<i>Colletotrichum gloeosporioides f.sp. aeschynomene</i>	Northern joint vetch	<i>Aeschynomene indica</i>
	-	<i>Alternaria macrospora</i> <i>Fusarium lateritium</i>	Velvetleaf	<i>Abutilon theophrasti</i>

	-	<i>Alternaria macrospora</i> <i>Puccinia heterospora</i>	Spurred anoda	<i>Anoda cristata</i>
	Culmorum	<i>Fusarium roseum</i>	Waterhyme	<i>Hydrilla verticillata</i>

Qualities/characteristics of Biocontrol agents

- Ecological compatibility- they should not harm the natural ecology of that region
- Climatic adaptability- they should adopt to various climatic conditions
- They should have a higher multiplication ratio
- They can survive low populations of hosts or prey and multiply as needed.
- They should have strong ability to find hosts or prey.
- They should have host specificity
- They should not affect the main crop or beneficial insects
- They should not cause hyper parasitism
- They should provide control of insect pests, diseases & weeds for an extended time.
- They should be easily culturable in laboratory

Role of Biocontrol agents

The biocontrol agents assist the organic farmers in controlling the pests, diseases & weeds in an effective way. When used correctly the bio agents can reduce the crop loss by half. While they cannot manage these issues entirely on their own, they play a vital role in organic farming.

Conclusion

As we all know, Organic farming is the booming sector in agriculture as the people are being conscious about what they consume. The organic farmers are having very small plots, as they are not able to supply the demand. However, increased pests, diseases, and weeds impact their productivity and the availability of organic products. Therefore, using biocontrol agents can help organic farmers reduce losses and provide higher quality products to consumers.

References

1. Indian Council of Agricultural Research (ICAR) – National Bureau of Agricultural Insect Resources (NBAIR). (2021). *Biocontrol agents and their utilization in Indian agriculture*. ICAR-NBAIR

2. Singh, A., & Singh, D. (2020). Role of biological control agents in sustainable organic farming: A review. *Journal of Entomology and Zoology Studies*, 8(2), 1102–1110.
3. Indian Council of Agricultural Research (ICAR). (2019). *Organic farming: Principles, practices, and prospects*. ICAR, New Delhi.
4. Tamil Nadu Agricultural University (TNAU). (2020). *Biological control of pests and diseases*. TNAU Agri tech Portal.
5. National Centre of Organic Farming (NCOF). (2018). *Manual on organic farming and biocontrol practices*. Ministry of Agriculture & Farmers Welfare, Government of India.



NATURAL PLANT-DERIVED TANNIC ACID AND ITS ROLE IN POST-HARVEST DISEASE MANAGEMENT

Article ID: AG-VO5-I12-82***Dr. Shalini Sharma and Dr. Sunita Chandel**

Department of Plant Pathology, College of Horticulture, Dr Yashwant Singh Parmar University
of Horticulture and Forestry Nauni-173 230, Solan (HP) India

*Corresponding Author Email ID : shaliniuhf11@gmail.com

Introduction

Fruits and vegetables hold immense significance not only in countries like India but globally as well. They are regarded as perishable crops when compared to grains, legumes, and oilseed crops. Most of the fruits and vegetables have substantial amount of water (around 70%–95% moisture content), possess larger size, smooth texture, and exhibit high respiration rates which collectively creates favourable environmental conditions for the growth of various pathogens which causes certain diseases between the period of harvest and consumption. Post-harvest spoilage results in significant losses, especially in developing nations like India, where it can exceed more than 40% (Anand and Barua, 2022). The primary cause of post-harvest spoilage in fruits and vegetables are predominantly fungi and bacteria. In recent decades, the rising demand for fresh produce has driven the food industry to innovate various techniques that can slow down post-harvest deterioration. Currently, synthetic fungicides are being used extensively to minimize losses after crop harvesting. However, the excessive and prolonged use of these chemicals has resulted in adverse effects such as development of pathogen resistance, contamination of soil and water bodies and risks to human health.

Natural plant-derived products are considered as good substitute for the management of postharvest diseases. Tannic acid is a naturally occurring plant polyphenolic compound that comes under the category of tannins and is widely distributed in numerous plant species with diverse bioactivities, including antidiabetic, anticancer, antioxidative and antimicrobial properties and is generally recognized as safe in the food industry (Cosme et al., 2025). It is

found in various parts of the plants such as fruits, leaves, and barks. Tannic acid is being studied for exploring its potential role in managing post-harvest disease of mainly horticulture crops. A group of scientists observed that when tannic acid is introduced into water, it tends to coat anything that is placed in the water.

This phenomenon applies to a range of materials, including metals, plastics and even viruses. The researchers exploited this phenomenon by introducing iron ions into the mixture. They observed that these ions stuck to the acid molecules, resulting in the formation of a thin film. Subsequently, they introduced other substances into the mixture to act as substrates and found that the acid-iron films would automatically coat each of these materials. In the case of small particles, this process led to the creation of small capsules. The researchers also observed that by adjusting the pH level of the solution containing the coating, the coating could dissociate itself (Ejima et al., 2013). This finding has paved the way for the creation of simple and cost-effective coatings.

The potential role of tannic acid in post-harvest disease management includes:

Antifungal Activity: Tannic acid has been found to possess antifungal properties. It can inhibit the growth of certain fungal plant pathogens that causes post-harvest diseases in fruits and vegetables. Harvested crops treated with tannic acid might be able to reduce the risk of fungal contamination and prolongs the shelf life of the harvested produce.

Antioxidant Properties: Tannic acid possess antioxidative properties, which aids in averting oxidative stress and deterioration of harvested produce. Oxidative stress causes various diseases and the deterioration of harvested produce during storage period. The antioxidative impact of tannic acid could potentially uphold the quality of agriculture crops over an extended duration.

Phenolic Compounds: Tannic acid is part of group of phenolic compounds, which have been associated with various health benefits, including antimicrobial properties. These properties could potentially contribute to reducing the growth of pathogens responsible for post-harvest diseases.

Preventive Treatment: Tannic acid could potentially be used as a preventive treatment for the storage and transportation of harvested produce by coating the surface of fruits and vegetables with tannic acid-based formulations which might form a shielding barrier that could inhibits the growth and further dissemination of plant pathogens.

Natural Alternative: Tannic acid is a naturally occurring compound, which holds the promise to be used as a natural substitute to synthetic fungicides for the disease management. It holds the potential value for organic or sustainable agricultural practices.

Disease Management

The studies have found that tannic acid demonstrates antifungal activity against various postharvest pathogens and can be used as a potential bioactive compound for the post-harvest disease management. Tannic acid and its derivatives makes a stable metal-organic coordination complex with metal ions, especially Fe(III), and these metal-organic coordination complex nanofilms forms immediately upon mixing of Fe(III) and TA solutions. Sprayed nanocoating using the Fe(III)–TA complex increased the shelf life for mandarin oranges and strawberries.

Coating with TA (10Mm) and 10mM Fe(III) for 5 sec preserved mandarin oranges for 14 days at 25 °C temperature, while uncoated ones rotted. After 28 days, 27% uncoated oranges spoiled; coated ones remained intact without any fungal contamination. Under field conditions, 5mM TA and Fe(III) solutions simultaneously sprayed for 3 sec on strawberries, washed and harvested after 58 h, unsprayed strawberries were rotten with white mould growth but sprayed strawberries stayed fresh (Park et al., 2017). In another study, TA-cross-linked zein coating extended guava shelf life by 3–4 days versus uncoated fruits. Zein is a corn storage protein which is isolated from corn gluten meal with wide applications like films and pharmaceuticals products. Zein is rich in large amount of hydrophobic amino acids and that is why zein films show low water vapor permeability and effective gas barrier properties resulting in decreasing O₂ and CO₂ exchange and retards respiration rate of the harvested produce. Zein coatings benefited pears, mangoes, and dates; tannic acid crosslinking have been reported to boosts zein film strength and water resistance (Santos et al., 2018).

Shellac, a natural lipid polymer sourced from the *Kerriar lacca* insect secretion, is safe and used as a food coating due to its biodegradability, fast drying ability, moisture resistance and barrier properties. This insect thrives on some types of trees mainly in countries like China, India and Thailand and has high safety profile approved by the US Food and Drug Administration. It extends the shelf life of strawberries, apples, and citrus fruits by creating a semi-permeable barrier against carbon dioxide, oxygen, and moisture that generates a modified atmosphere around the fruit surface. Despite it has many advantages as a coating, its use in fruit and vegetables preservation is significantly low due to some drawbacks, such as its limited

antimicrobial and antioxidant ability and weak bonding with fruit peel surface. However, in a study, when tannic acid was added to shellac coating, their combined effect extended the mango shelf life by enhancing antifungal activity when compared with shellac coating alone. The combination of tannic acid and shellac significantly prolonged mango shelf life and enhanced their overall quality compared to uncoated mango fruits.

The shelf life of mango fruits was extended by about 10 days while maintaining firmness and weight, slower respiration, improved physical and chemical attributes, browning suppression, reduced lipid peroxidation, aroma preservation and enzyme activity regulation. The addition of TA improved the antifungal impact of the coating (Ma et al., 2021). The findings suggest a synergistic effect between TA and shellac, highlighting their potential to effectively extend mango shelf life and enhancing quality.

The Black spot rot disease in apples caused by *Alternaria alternata*, is a major postharvest disease. The fungus produces mycotoxins which are harmful to human health, resulting in oesophageal cancer and fungal keratitis. Lab tests suggested that 5.0 mg mL⁻¹ tannic acid significantly hindered the growth and its spore germination. Immersion of fruits with tannic acid strongly reduced the development of spots on the fruit areas and also delayed softening of fruit during storage conditions (Wang et al., 2023).

Conclusion

Tannic acid is recognized as a promising natural compound for controlling post-harvest diseases in fruits and vegetables. Numerous studies have demonstrated its potent antifungal, antioxidant and antimicrobial properties. Tannic acid effectively suppresses major post-harvest pathogens, mitigates oxidative stress and preserves produce quality during storage and transport. Additionally, tannic acid forms stable metal-organic complexes, primarily with Fe(III) and interacts successfully with edible coating materials such as zein and shellac, thereby contributing to extended shelf life and improved fruit quality.

Studies have shown that tannic acid-based coatings and nanofilms reduce fungal decay, delay fruit softening, regulate respiration, prevent browning and maintain the physicochemical qualities of citrus, strawberries, guava, mango, apples, pears, and dates after harvest. The synergistic effects of tannic acid combined with natural polymers highlight its potential as an ecofriendly alternative to synthetic fungicides in organic and sustainable postharvest management systems.

Despite the promising laboratory and field results, further research is required before tannic acid can be widely adopted in post-harvest management. Standardization of factors such as concentration, crop type, pathogen variability, coating formulation, application method and cost-effectiveness for large-scale use is necessary. Additional research and pilot trials are essential to develop commercially viable technologies based on these findings. Overall, tannic acid represents a sustainable chemical approach with significant potential to reduce post-harvest losses and enhance food quality and safety in modern agriculture.

References

- Anand, S., Barua, M. K. 2022. Modeling the key factors leading to post-harvest loss and waste of fruits and vegetables in the agri-fresh produce supply chain. *Comput. Electron. Agric.* 198: 106936.
- Cosme, F., Aires, A., Pinto, T., Oliveira, I., Vilela, A., Gonçalves, B. 2025. A comprehensive review of bioactive tannins in foods and beverages: functional properties, health benefits, and sensory qualities. *Molecules.* 30(4): 800.
- Ejima, H., Richardson, J. J., Liang, K., Best, J. P., van Koeveerden, M. P., Such, G. K. et al. 2013. One-step assembly of coordination complexes for versatile film and particle engineering. *Science.* 341(6142): 154-157.
- Ma, J., Zhou, Z., Li, K., Li, K., Liu, L., Zhang, W. et al. 2021. Novel edible coating based on shellac and tannic acid for prolonging postharvest shelf life and improving overall quality of mango. *Food Chem.* 354: 129510.
- Santos, T. M., Men de Sá Filho, M. S., Silva, E. D. O., da Silveira, M. R., de Miranda, M. R. A., Lopes, M. M., Azeredo, H. M. 2018. Enhancing storage stability of guava with tannic acid-crosslinked zein coatings. *Food Chem.* 257: 252-258.
- Wang, H., Fu, L., Li, C., Zhang, X., Narcisse, K. E., Qi, H. et al. 2023. Tannic acid exerts antifungal activity *in vitro* and *in vivo* against *Alternaria alternata* causing postharvest rot on apple fruit. *Physiol. Mol. Plant Pathol.* 125: 102012.

Volume: 05 Issue No: 12

WOMEN AT THE HEART OF GLOBAL AGRICULTURE: A NEW ERA OF RECOGNITION, RIGHTS, AND LEADERSHIP

Article ID: AG-VO5-I12-83

Easwaran Cheran^{1, #}, Moorthy Gokulakrishnan^{2, 3, #}, and Sharmila Rahale Christopher^{1, *}

¹ Centre for Agricultural Nanotechnology, Directorate of Natural Resource Management, Tamil Nadu Agricultural University, Coimbatore, India 641003

² Indian Council of Agricultural Research-Indian Institute of Agricultural Biotechnology, Ranchi, India-834003

³ Indian Council of Agricultural Research-Indian Agricultural Research Institute, Pusa, New Delhi, India-110012.

*Corresponding Author Email ID: sharmila.r@tnau.ac.in

Abstract

Women farmers grow nearly half of the world's food, yet their work remains undervalued, underreported, and under-supported. In response, the United Nations has declared **2026 as the International Year of the Woman Farmer**, placing a long-overdue spotlight on the women who plough fields, manage farms, build agri-enterprises, and lead rural communities. New global platforms especially the information hub launched by the National Association of State Departments of Agriculture (NASDA) and 15 partner organizations aim to amplify women's voices, expand leadership opportunities, and address the deep-rooted inequalities they face. In India, institutions like **ICAR-Central Institute for Women in Agriculture (CIWA)** and government schemes play a critical role in supporting women's participation. This article explores the global and national landscape of women in agriculture, the barriers they continue to confront, the policy breakthroughs underway, and why empowering women farmers is key to food security, climate resilience, and rural prosperity.

Introduction

Across continents, from mechanized farms in the United States to smallholder fields in South Asia, women are indispensable to agriculture. They plant, weed, harvest, preserve seed,

manage livestock, operate machinery, and increasingly run family farms on their own. Yet despite forming 43% of the global agricultural workforce, women consistently face structural barriers in land ownership, finance, training, technology, and market access. Their contributions are immense, but their recognition is minimal.

This imbalance is finally beginning to shift. The launch of the International Year of the Woman Farmer marks a historic moment for the agricultural sector. The initiative seeks not only to honor women farmers but to correct decades of gender disparity and reshape agricultural systems to be more inclusive, equitable, and efficient.

A Global Platform for Women Farmers

In October 2024, on the International Day of Rural Women, a new global information hub went live a collaborative effort involving NASDA and major agricultural organizations worldwide. The hub is the first visible component of a coordinated United States–led initiative that will culminate in 2026.

Its purpose is clear:

to make women’s roles visible, gather evidence, share tools, and push for stronger leadership pipelines.

For decades, global data has shown that women farmers work longer hours, often without pay, and carry the additional burden of household responsibilities. They are central to food production yet remain excluded from leadership positions and research agendas. The new hub tackles this gap by documenting real stories, spotlighting innovations led by women, and providing data-driven recommendations for governments and industries.

A cornerstone of this effort is the National Women in Agriculture Study led by the American Farm Bureau Federation. With 1.2 million female agricultural producers in the United States-36% of all producers, the study aims to map leadership trends, identify barriers, and highlight opportunities for women across the sector. Insights from the study will be unveiled at the ACE Summit (Advocate, Cultivate, Empower) in June 2026.

Why This Initiative Matters

The agricultural community is increasingly recognizing that empowering women is not a symbolic gesture, it is a practical necessity. Women are essential to the sustainability of farming systems, yet they constantly face:

- Restricted access to land

- Limited credit and financial services
- Technology gaps
- Market exclusion
- Low representation in leadership

Research has repeatedly shown that closing these gender gaps can increase agricultural productivity by up to 30%, improve food security, and stimulate rural economic growth. The International Year of the Woman Farmer aims to turn evidence into action and action into systemic reform.

India's Landscape: The Feminisation of Agriculture

India exemplifies both the strength and struggle of women in agriculture. While 80% of rural women are engaged in agricultural activities, very few hold land titles. Women account for:

- 3.6 crore women farmers
- 6.15 crore women agricultural labourers
- 33% of agricultural labor force
- 48% of self-employed farmers

As men migrate to urban centers for jobs, women increasingly manage farms independently—a phenomenon widely termed the "feminisation of Indian agriculture."

Their roles go far beyond cultivation. Women are community organizers, natural resource managers, custodians of indigenous seeds, livestock caregivers, and key drivers of climate adaptation practices.

The Indian Institution Leading Gender Research: ICAR–CIWA

India is one of the few countries with a dedicated institution for gender issues in agriculture: the ICAR–Central Institute for Women in Agriculture (CIWA), established in 1996 in Bhubaneswar. CIWA's mandate includes:

- Conducting gender-focused agricultural research
- Designing technologies suited for women
- Facilitating participatory action research
- Bringing women's perspectives into agricultural R&D programmes

As gender roles evolve with socio-economic change, the need for such institutions has grown exponentially. CIWA continues to generate evidence and innovations that support women's participation, skill enhancement, and economic empowerment.

Challenges Women Farmers Continue to Face

Despite their critical involvement, women farmers encounter systemic barriers:

1. Low Land Ownership

Women own only 14% of agricultural land, and NFHS-5 reports only 8.3% ownership in their name. Lack of land titles prevents access to:

- Bank loans
- Subsidies
- Crop insurance
- Agricultural training

2. Limited Access to Technology and Credit

With constrained financial resources and fewer training opportunities, women adopt new technologies at a slower pace, which affects productivity.

3. Invisible and Unpaid Workload

Women juggle fieldwork with household chores, water collection, food preparation, and childcare resulting in time poverty and physical strain.

4. Market Exclusion

Mobility restrictions, unequal bargaining power, and discrimination prevent women from accessing profitable markets and fair prices.

5. Climate Vulnerability

Climate change intensifies the challenges women face floods, droughts, and erratic weather disproportionately affect smallholder women farmers who already lack resources.

Government Policies and Innovations Supporting Women Farmers

India has rolled out several gender-focused programmes:

Mahila Kisan Sashaktikaran Pariyojana (MKSP)

Strengthens skills, capacity building, and sustainable agricultural livelihoods for women.

Sub-Mission on Agricultural Mechanization (SMAM)

Offers subsidy assistance to help women purchase farm machinery.

National Food Security Mission (NFSM)

Reserves 30% of its budget for women farmers.

Namo Drone Didi Initiative (2024–26)

Empowers 15,000 women SHGs with drones for farm services a major step toward technological

inclusion.

Self-Help Groups and Microfinance Models

Enhance collective action, entrepreneurial growth, and financial inclusion.

State-Level Schemes

Such as Mahila Kisan Yojana, micro-irrigation subsidies, and skill training initiatives.

Community-Based Innovations

Projects like **ENACT in Assam**, which disseminate climate advisories to women using mobile technology, help improve resilience and productivity.

The Labour Burden and Diversity of Women's Agricultural Work

Time-use surveys across countries consistently reveal that:

- Women spend more hours on agricultural tasks than men.
- They dominate activities like weeding, harvesting, and seed selection.
- They perform the majority of unpaid household work, reducing opportunities for education or skill development.

Importantly, women's contributions differ by region, crop, socio-economic class, and culture. Understanding this diversity is crucial for designing effective policies and technologies.

The Road Ahead: What Must Change?

1. Use 2026 as a Catalyst

The International Year of the Woman Farmer should be used to launch long-term reforms, not symbolic celebrations.

2. Build Gender-Responsive Agricultural Policies

Policies should be rooted in **gender-disaggregated data**, recognizing women's specific constraints.

3. Secure Land and Resource Rights

Reforming inheritance laws, land leasing, and title registration is essential.

4. Strengthen Women-Led Farmer Producer Organizations (FPOs)

Collective strength enhances bargaining power, market access, and decision-making.

5. Expand Technology Access

From drones and sensors to improved seeds and mechanization, women must be equipped to lead modern agriculture.

Conclusion

The declaration of **2026 as the International Year of the Woman Farmer** marks a turning point in global agricultural discourse. Women farmers are not invisible helpers, they are **entrepreneurs, innovators, leaders, and custodians of food security**. Empowering them is not only a matter of fairness but a strategic necessity for achieving sustainable agriculture, climate resilience, and rural prosperity. The world has finally begun to listen. Now, it must act by redesigning agricultural systems that acknowledge women not as secondary participants, but as transformative agents shaping the future of global food systems.



SMART TERRACING FARMING : PREVENTION FROM FLOODS & LANDSLIDES IN FARMLANDS

Article ID: AG-VO5-I12-084**Harish B P* and Gowtham A M**

*Ph.D. scholar, Department of Agricultural Extension Education, UAS, GKVK, Bangalore

PG scholar, Dept. of Agricultural Extension Education, UAS, Dharwad, Karnataka, India

*Corresponding Author Email ID: harishagriculture52@gmail.com

Abstract

Smart terracing farming is an innovative agricultural approach that integrates traditional terracing with modern technologies such as remote sensing, IoT and early warning systems to combat floods and landslides in sloped farmlands. This method enhances soil conservation, water management and disaster resilience. By utilizing sensors, drones and automated systems farmers can make data-driven decisions to improve productivity and sustainability. Despite challenges like high costs and technical demands smart terracing presents a promising solution for climate-resilient and sustainable agriculture in vulnerable regions.

Introduction

Agriculture in hilly and sloped terrains is increasingly threatened by natural disasters particularly floods and landslides which are becoming more frequent and severe due to climate change and anthropogenic land degradation. These events not only damage crops and infrastructure but also lead to long-term soil erosion, nutrient loss and declining agricultural productivity. For millions of smallholder farmers who depend on these fragile ecosystems the impact is devastating both economically and ecologically. Terracing, a traditional technique involving the construction of step-like flat surfaces on slopes has long been used to control water runoff and prevent soil erosion. However, with rising climate variability and increased pressure on land, conventional terracing alone is no longer sufficient.

Landslides are a significant geo-environmental hazard, particularly in hilly and mountainous regions where agriculture is practiced on sloped terrains. Triggered primarily by

intense rainfall, deforestation, improper land use and seismic activity, landslides involve the sudden movement of soil, rock and debris down a slope.

Floods are among the most frequent and destructive natural disasters affecting agriculture worldwide. Characterized by the overflow of water onto land that is usually dry floods can result from intense rainfall, river overflows, dam failures or rapid snowmelt. In agricultural regions, especially those located in low-lying or sloped terrains, floods cause **devastating impacts** washing away topsoil, destroying crops, eroding field boundaries, and damaging infrastructure such as irrigation channels and farm roads.

Smart Terracing Farming

Smart terracing farming combines traditional terracing methods with sophisticated modern technology such as remote sensors, drone sensing and laser scanning to create a more resilient and efficient farming system. By combining **traditional wisdom with modern engineering** it not only enhances agricultural productivity but also plays a crucial role in **disaster risk reduction**, soil conservation and sustainable rural development. Promoting this approach in vulnerable areas can safeguard both **farmlands and farmer incomes** in the face of climate adversity.

Remote sensing: With the help of drones, information about the terrace area can be obtained from a distance. This method allows high-precision mapping of the terrace ground surface through a software capable of 3D reconstruction. It can be used to detect, understand or even predict land degradation, for example by simulating the flow of water and sediments across a terrace. Such a workflow enables efficient scenario analyses of new terrace interventions or climatic conditions. Soil protection works can be guided by this workflow for a rapid and low-cost evaluation of new designs. Automatic detection offers a powerful tool in rapid inventorying and monitoring of soil degradation at landscape scale.

Soil Moisture Sensors: These sensors monitor the soil moisture levels in real-time, providing data on when and how much to irrigate, preventing both over-irrigation and under-irrigation.

Weather Sensors: Devices that collect data on local weather conditions, including rainfall, temperature, and humidity. This information can predict heavy rains or droughts, allowing farmers to take preemptive measures.

Landslide Sensors: These sensors detect ground movements and shifts, providing early warnings of potential landslides. This allows for timely evacuation and protective measures.

Water Flow Sensors: Installed in irrigation systems, these sensors monitor the flow and distribution of water, ensuring efficient water use and reducing runoff.

Data Integration and Analysis

IoT (Internet of Things): The Internet of things (IoT) describes devices with sensors, processing ability, software and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks. Sensors can be connected through IoT, enabling real-time data collection and transmission to a central system.

Data Analysis: Advanced analytics and machine learning algorithms process the data, providing actionable insights and predictive models for better decision-making.

Automated Systems: Integration with automated irrigation and drainage systems that can adjust based on sensor data, optimizing water usage and protecting the land.

Early warning systems - landslide prediction with remote-sensing techniques: Landslides are widespread occurrences that can become catastrophic when they occur near settlements and infrastructure. Detection, monitoring and prediction are fundamental to managing landslide risks and often rely on remote-sensing techniques (RSTs). Ground-based sensors are increasingly used in real-time monitoring and early warning of landslides. Early warning systems for slope instability are needed to alert users of accelerating slope deformation behavior, enable evacuation of vulnerable people, and conduct timely repair and maintenance of critical infrastructure.

Slope Alarms approach: The Slope ALARMS approach uses a battery-operated sensor that can monitor acoustic emissions (AE) in real time, which provides alert messages to professionals who then decide on actions to be taken.

Community Slope Safe approach (CSS): This is a simpler and lower cost AE-based system than the Slope Alarms. It needs to be looked after by a community. Non-specialists can install and maintain the system. It is intended that technical support for installation, setup and troubleshooting would be provided by a small team located in a region. Humanitarian and/or government funding sources could provide hundreds of CSS systems in a region prone to landsliding. The community would also be guided to develop emergency response plans in case of an alert being triggered.

IoT-Based Early Landslide Detection System: Landslide detection based on Internet of Things (IoT) and Wireless Sensor Networks (WSN) offers accurate real-time detection. WSN captures

significant IoT data of the geomorphology of landslide prone areas which can be monitored remotely. IoT hardware uses sensors like soil moisture sensor, rain gauge, pore pressure sensor and vibration sensors. The data is characterized and analyzed in the Cloud, based on machine learning algorithms. The possible landslide alert and real time monitoring data of environmental variables can be seen in mobile applications. The IoT based Landslide detection system is able to predict possible landslides.

Sirens: Stand-alone solar-powered electronic sirens are important for landslide early warning systems, providing a reliable and independent source of emergency notification even in remote areas with limited infrastructure or power outages. The seamless communication with sirens allows control centers to monitor siren status and activate alarms from a centralized location.

SWOT Analysis

Strengths (What Works Well)

- 1. Encourages Sustainable Land Use:** Sloped and marginal lands can be effectively utilized for cultivation.
- 2. Soil Preservation and Erosion Control:** Terraces reduce runoff and help in conserving topsoil, preventing degradation.
- 3. Increased Crop Yields:** By maintaining soil structure and fertility, terraces support better crop productivity.

Weaknesses (What Is Lacking)

- 1. Vulnerability to Extreme Weather:** Heavy rainfall and floods can damage terraces, especially if poorly constructed.
- 2. High Initial Cost and Investment:** Construction and setup require significant financial resources.
- 3. Technical Skills Required:** Building and maintaining terraces demand skilled labor and training.

Technology Dependency: Some smart systems depend on sensors or automated inputs that may be complex to manage in rural contexts.

Opportunities (What Works in Favor)

- 1. Technological Integration:** Use of data-driven tools, sensors, and automation increases efficiency.
- 2. Adaptability:** Can be implemented in various terrains and climates.

3. Environmental Benefits: Promotes soil and water conservation and reduces land degradation.

Threats/Challenges in Implementation

1. Technical Failures: Poorly maintained or designed systems may malfunction.

2. Financial Risks and High Costs: Upfront investment may not be feasible for smallholders.

3. Complexity of Early Warning Systems: These systems may be too expensive or technologically demanding for low- and middle-income countries.

Conclusion

Smart terracing farming is an agricultural technique designed to prevent land degradation, particularly from floods and landslides, in farmlands. Our proposal of smart terracing farming integrates terracing techniques with modern technology, offering a multifaceted solution to this pressing problem. The incorporation of **remote sensors**, drone sensing, and laser scanning into terracing methods provides a robust system that significantly reduces soil erosion and surface runoff, thereby mitigating the risks of floods and landslides. By implementing early warning systems and advanced data analytics, farmers can make informed decisions about irrigation, crop management, and emergency responses. This not only enhances agricultural productivity but also safeguards local communities from the devastating impacts of extreme weather events. Overall, the adoption of smart terracing farming exemplifies innovative solutions can serve as a model for sustainable agriculture in other regions facing similar challenges, and leading to more resilient farming system.

References

FAO, (2011). *Terracing for Soil and Water Conservation*. Food and Agriculture Organization of the United Nations.

Lal R., (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*. 7(5): 5875–5895.

Zhang C. and Kovacs J.M., (2012). The application of small unmanned aerial systems for precision agriculture: A review. *Precision Agriculture*. 13(6): 693–712.

United Nations Office for Disaster Risk Reduction (UNDRR), (2019). *Global Assessment Report on Disaster Risk Reduction*.

Bianchini S., Casagli N., Righini G., Lagomarsino D. and Moretti S., (2015). Landslide monitoring using multi-temporal satellite SAR data: Analysis and examples. *Remote Sensing*. 7(12): 15244–15267.

- Ramesh M.V., (2014). Design, development, and deployment of a wireless sensor network for detection of landslides. *Ad Hoc Networks*. 13: 2–18.
- Ayalew L. and Yamagishi H., (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan. *Geomorphology*. 65(1-2): 15–31.
- Hurni H., (1990). Degradation and conservation of soil resources in the Ethiopian Highlands. *Mountain Research and Development*. 10(2): 123–130.



Volume: 05 Issue No: 12

CACTUS PEAR: THE FUTURE CROP OF ARID ZONES - A MORPHOLOGICAL, PHYSIOLOGICAL, AND NUTRITIONAL OVERVIEW

Article ID: AG-VO5-I12-85

Meena E^{1*}¹ Department of Fruit Science, HC&RI, TNAU, Coimbatore, Tamil Nadu

Corresponding Author Email ID: meenaelangovan25@gmail.com

Abstract

Cactus pear (*Opuntia ficus-indica*) is a strategic crop for arid and semi-arid zones, driven by its exceptional drought tolerance. This review outlines its core strengths: morphology, CAM physiology, and nutritional value. The plant's succulent cladodes enable water storage and feature CAM (Crassulacean Acid Metabolism) a water-saving process where CO₂ is fixed at night. The fruit (tunas) and pads (nopales) are rich in antioxidants (Betalains), fiber, and water, making them valuable for human health. Beyond food, cactus pear is vital as livestock feed during drought and crucial for soil stabilization and carbon sequestration. Research must focus on genomics and breeding to maximize its global potential for food security and climate adaptation.

Keywords: Cactus pear, Arid Zone, CAM plant, fruit

Introduction

Cladodes are flattened, succulent stems that function as the primary photosynthetic and water-storage organs of *Opuntia ficus-indica*. They possess a thick waxy cuticle and a highly cutinized epidermis that reduce water loss, while the underlying parenchyma contains mucilage-rich vacuoles that regulate water balance during drought.



The outer chlorenchyma layer supports CAM-based CO₂ fixation, making the cladode a multifunctional structure essential for survival in arid environments.

Morphological Characteristics

Cladodes

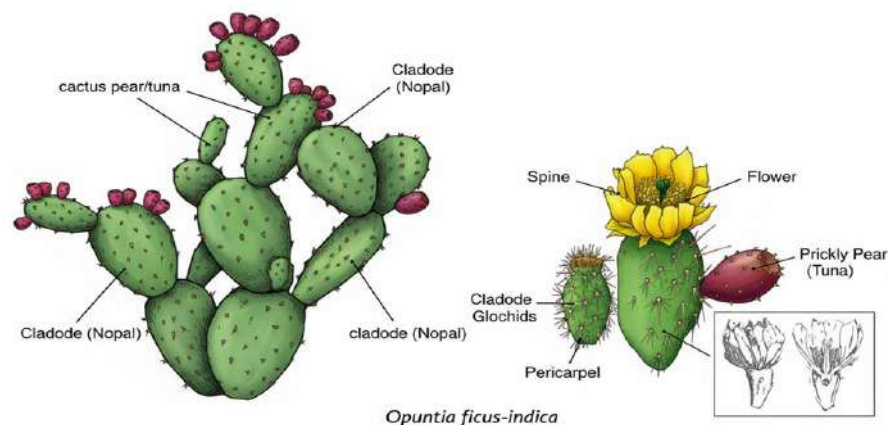
Cladodes are flattened, succulent stems that function as the primary photosynthetic and water-storage organs of *Opuntia ficus-indica*. They possess a thick waxy cuticle and a highly cutinized epidermis that reduce water loss, while the underlying parenchyma contains mucilage-rich vacuoles that regulate water balance during drought. The outer chlorenchyma layer supports CAM-based CO₂ fixation, making the cladode a multifunctional structure essential for survival in arid environments

Areoles

Areoles are specialized meristematic units arranged in spiral series across the cladode and act as developmental center for new cladodes, flowers, fruits, and adventitious roots. They also produce spines and glochids, reflecting their combined role in defense and vegetative propagation. This unique morphology gives cactus pear its remarkable regenerative capacity, allowing rapid recovery from physical damage or environmental stress.

Spines and Glochids

Spines in *O. ficus-indica* are modified leaves that provide mechanical defense against herbivores while also helping create a boundary layer that reduces transpiration. Glochids, the smaller barbed bristles, detach easily and act as an additional protective mechanism while enhancing microclimate stability on the cladode surface. Together, these structures improve the plant's drought tolerance by limiting heat load and water loss.



Root System

The root system of cactus pear is shallow but highly adaptive, enabling rapid uptake of moisture from light and sporadic rainfall. A fleshy taproot provides anchorage, while lateral roots spread horizontally to capture surface water. During rainfall, the plant develops temporary rain roots that emerge within hours to maximize water absorption and then senesce when the soil dries, a unique adaptation that prevents reverse water loss and supports survival in extreme drought.

Flowers

Flowers of cactus pear are large, hermaphroditic, and usually borne along the margins of cladodes. Their morphology, including a tuberculated pericarp with spiral areoles, supports pollination by nocturnal insects, moths, and bats, which is advantageous in hot climates where daytime floral activity would increase water loss. This floral structure ensures effective reproduction even under harsh environmental conditions.

Fruit (Tuna)

The fruit of *O. ficus-indica* is a fleshy berry varying in size and color, typically ranging from green and yellow to red and purple. The thick rind contains glochids while the inner pulp is rich in sugars, vitamins, minerals, and antioxidants, making it nutritionally valuable. Numerous hard-coated seeds are embedded in the pulp, contributing to the fruit's high dietary fiber content and its importance in traditional diets and processing industries.

Physiological Characteristics

Crassulacean Acid Metabolism (CAM)

Cactus pear utilizes Crassulacean Acid Metabolism, a photosynthetic pathway that allows stomata to open at night for CO₂ uptake while remaining closed during the day, thus minimizing water loss. At night, CO₂ is fixed as malic acid and stored in vacuoles, while daytime decarboxylation releases CO₂ internally for photosynthesis. This temporal separation greatly enhances water-use efficiency, allowing the plant to thrive in environments where C₃ and C₄ crops cannot survive.

Water Storage and Mucilage Function

The succulent cladodes act as internal reservoirs, storing large amounts of water that sustain the plant through prolonged drought. Mucilage, a hydrogel composed of complex polysaccharides, stabilizes cellular hydration by regulating osmotic pressure and preventing

tissue collapse during dehydration. This physiological trait enables rapid recovery after rainfall and provides mechanical buffering against extreme temperature fluctuations.

Nutritional Value and Health Benefits

Cactus pear fruits (tunas) are highly hydrating and rich in vitamins **C and E**. They are distinguished by their high content of **betalain pigments**, which are powerful antioxidants that protect cells from stress. The fiber and mineral content, including essential **potassium**, support heart and metabolic health. These bioactive compounds give tunas potential therapeutic benefits, including anti-inflammatory and blood-sugar-regulating effects.

Applications in Food, Feed, and Environment

Human Consumption

Both the tender pads (nopales) and the fruit (tunas) are valuable foods. Nopales are used in savory dishes and salads, while tunas are processed into juices, jams, and nutraceuticals. The increasing demand highlights its promise as a functional, health-promoting ingredient in modern diets.

Livestock Feed

Spineless cactus pads are a critical, water-rich forage source for livestock in arid regions. Its high palatability and water content (up to 90%) sustain cattle and goats during severe drought, significantly reducing the need for supplemental water. It is an economical and resilient feed solution for dryland farming.

Environmental Functions

Cactus pear is a key tool for climate adaptation. Its CAM photosynthesis is highly water-efficient, allowing it to sequester carbon and survive extreme drought. The dense plant structure and root system are crucial for soil stabilization and preventing erosion on degraded or desertified lands.

Future Aspects

Future focus must be on genomics and breeding to develop superior, spine-free, high-yield cultivars with enhanced stress tolerance. Economic research is needed to validate the feasibility of large-scale commercial production in developing regions. Addressing postharvest and processing innovations will be essential to unlock its full potential for global food security and land restoration.

References

- Nobel, P. S. Cactus Physiology. Univ. California Press, 2002. (Synthesized for xerophytic adaptations and cladode structure)
- Nefzaoui, A., Louhaichi, M. 2013. The Cactus Pear: A New Source of Water, Food, and Feed. Food and Agriculture Organization of the United Nations (FAO). (Synthesized based on multiple sources detailing global use and FAO reports)
- Monjil, A. B., Taha, M. S., Monjil, M. A. A., Hossain, M. T., Hasan, M. A., Islam, M. S., et al. 2023. Physicochemical, Nutritional, and Medicinal Properties of *Opuntia ficus-indica* (L.) Mill. and Its Main Agro-Industrial Use: A Review. *Molecules* **28**(7): 1512. (Source for chlorenchyma, parenchyma, and general composition)



Volume: 05 Issue No: 12

INNOVATIVE AGRICULTURAL PRACTICES: ADVANCING SUSTAINABLE FARMING FOR THE FUTURE

Article ID: AG-VO5-I12-86**Priyanka M. Ramteke***

Assistant Professor, Shri Shivaji Science College Amravati, Shivaji Nagar, Morshi Road,
Amravati (M.S.) 444603 India

*Corresponding Author Email ID: priyanka.ramteke753@gmail.com

Abstract

The global demand for food, fiber, and fuel is increasing due to rapid population growth and climate change. Traditional farming practices alone are no longer sufficient to meet these demands sustainably. Innovative agricultural practices that leverage modern technologies, ecological approaches, and resource efficiency are revolutionizing the way we cultivate crops and rear livestock. This article explores key innovations in agriculture—such as precision farming, vertical farming, biotechnology, and integrated pest management—and their role in enhancing productivity, reducing environmental impact, and ensuring food security.

1. Introduction

Agriculture is at the heart of human civilization and economic development. However, unsustainable practices, soil degradation, water scarcity, and climate variability pose significant threats to agricultural productivity. In response, innovative agricultural practices are being adopted globally to improve yield, conserve resources, and adapt to environmental changes.

2. Precision Agriculture

Precision agriculture (PA) involves the use of GPS, sensors, drones, and data analytics to monitor field variability and manage crops at a micro level. PA allows farmers to apply fertilizers, pesticides, and water more efficiently, reducing waste and environmental impact.

Example: Variable Rate Technology (VRT) allows differential application of inputs based on real-time data, enhancing resource use efficiency (Zhang et al., 2002).

3. Vertical and Urban Farming

Vertical farming utilizes stacked layers of crops grown in controlled environments. It reduces land use and can be practiced in urban areas, minimizing food miles and offering year-round production.

Example: LED lighting and hydroponics in vertical farms can increase yield per unit area by up to 10 times compared to traditional farming (Despommier, 2010).

4. Climate-Smart Agriculture (CSA)

CSA integrates sustainable farming practices that improve productivity, resilience, and carbon sequestration. It includes crop diversification, conservation tillage, and agroforestry.

Example: Agroforestry systems improve soil fertility and provide shade, which can help reduce crop stress during heatwaves (FAO, 2013).

5. Biotechnology and Genetically Modified Crops

Biotechnology allows for the development of crops with improved traits such as drought tolerance, pest resistance, and enhanced nutrition.

Example: Bt cotton and Bt corn have significantly reduced the use of chemical pesticides in countries like India and the USA (Qaim & Zilberman, 2003).

6. Integrated Pest Management (IPM)

IPM combines biological, cultural, physical, and chemical tools to manage pests in an ecologically and economically sound manner.

Example: Use of pheromone traps and natural predators has reduced pest incidence in rice and cotton fields in Asia (Kogan, 1998).

7. Use of Renewable Energy in Agriculture

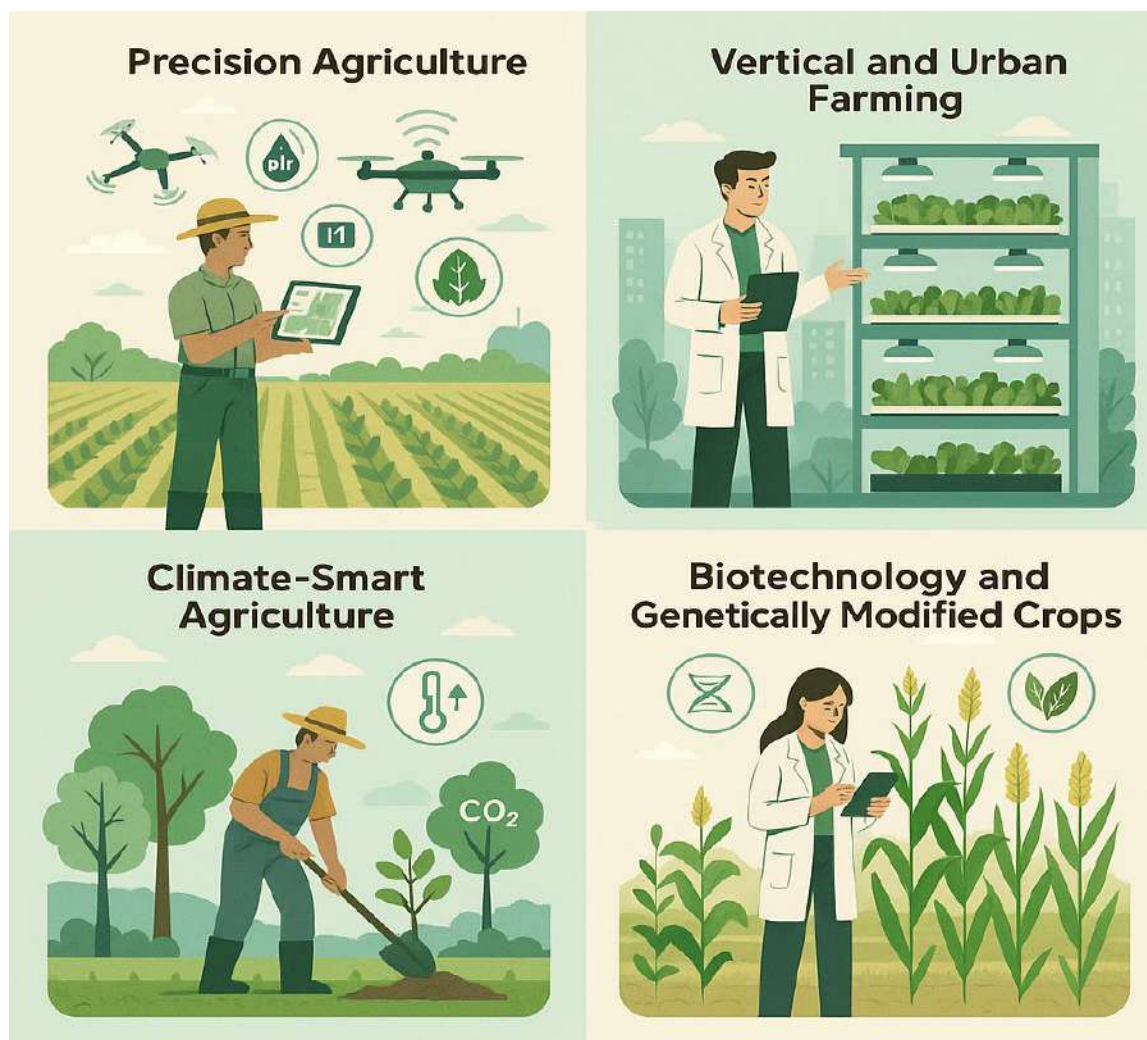
Solar-powered irrigation systems and biogas digesters are increasingly being used in farms, reducing dependency on fossil fuels and lowering greenhouse gas emissions.

Example: Solar pumps have improved irrigation access for smallholder farmers in India and sub-Saharan Africa, boosting productivity (Burney et al., 2010).

8. Digital Agriculture and AI

Artificial Intelligence (AI), machine learning, and mobile apps are enabling real-time decision-making and remote farm management.

Example: AI-based tools can predict pest outbreaks or recommend optimal planting schedules, enhancing productivity and risk management (Kamilaris et al., 2018).



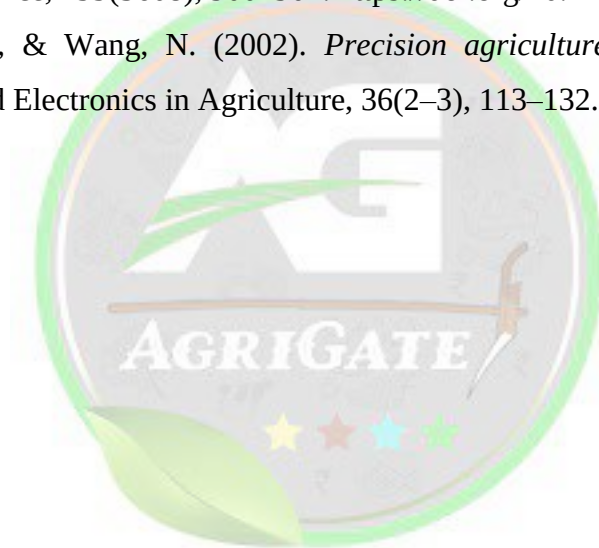
Conclusion

Innovative agricultural practices are transforming the way we produce food. By integrating technology, ecological principles, and sustainable resource management, these innovations offer viable solutions to the challenges of modern agriculture. Future policies and investments should support the adoption of these practices to ensure global food security and environmental sustainability.

References

Burney, J., Woltering, L., Burke, M., Naylor, R., & Pasternak, D. (2010). *Solar-powered drip irrigation enhances food security in the Sudano-Sahel*. Proceedings of the National Academy of Sciences, 107(5), 1848–1853. <https://doi.org/10.1073/pnas.0909678107>

- Despommier, D. (2010). *The Vertical Farm: Feeding the World in the 21st Century*. Thomas Dunne Books.
- FAO. (2013). *Climate-Smart Agriculture Sourcebook*. Food and Agriculture Organization of the United Nations.
- Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2018). *A review on the practice of big data analysis in agriculture*. *Computers and Electronics in Agriculture*, 143, 23–37. <https://doi.org/10.1016/j.compag.2017.09.037>
- Kogan, M. (1998). *Integrated pest management: Historical perspectives and contemporary developments*. *Annual Review of Entomology*, 43(1), 243–270.
- Qaim, M., & Zilberman, D. (2003). *Yield effects of genetically modified crops in developing countries*. *Science*, 299(5608), 900–902. <https://doi.org/10.1126/science.1080609>
- Zhang, N., Wang, M., & Wang, N. (2002). *Precision agriculture—a worldwide overview*. *Computers and Electronics in Agriculture*, 36(2–3), 113–132.



MICROBIAL BIOFILMS: HIDDEN SOIL WARRIORS

Article ID: AG-VO5-I12-87**Akhila Chandran S***

1 PhD scholar, Department of Soil science, College of agriculture, Vellayani,
Kerala Agricultural University, India

*Corresponding Author Email ID: chandranakhila7@gmail.com

Introduction

Healthy soil is the lifeblood of agriculture, supporting food production and the balance of ecosystems. Beneath our feet lies an intricate network of life teeming with microorganisms that perform essential roles in maintaining soil fertility and resilience. Among these, microbial biofilms are unsung heroes.

Biofilms are communities of microbes encased in a self-produced, protective matrix. This unique structure allows them to adapt to harsh conditions and function collectively to enhance soil health. By improving nutrient cycling, enhancing water retention, and fostering plant-microbe interactions, biofilms are becoming a cornerstone of sustainable agriculture. Their potential is especially promising in today's world, where excessive use of fertilizers, pesticides, and industrial pollutants has led to soil degradation. Recognizing their significance, scientists are exploring ways to harness biofilms for eco-friendly farming and environmental conservation.

How Biofilms Transform Soil Resilience

Soil resilience is the ability of soil to recover from stresses such as erosion, contamination, and loss of nutrients. However, modern farming practices and environmental changes have pushed soils beyond their natural limits, jeopardizing their ability to sustain life. This is where microbial biofilms step in.

Biofilms consist of water, microbial cells, and extracellular polymeric substances (EPS) that act as the backbone of their structure. This EPS matrix helps bind soil particles, promoting the formation of aggregates that improve soil structure and stability. Additionally, biofilms

enhance soil's water-holding capacity, helping crops survive droughts and erratic rainfall. Biofilms also play a crucial role in nutrient cycling. By facilitating the exchange and transformation of essential elements like nitrogen, phosphorus, and carbon, they create an environment where plants can thrive. This interaction not only boosts soil fertility but also reduces dependency on chemical fertilizers, paving the way for sustainable farming practices.

For example, biofilms formed by bacteria like *Bacillus subtilis* and *Pseudomonas* species have shown remarkable efficiency in improving soil health and crop productivity. These biofilms work synergistically with plant roots, enhancing nutrient availability and stress tolerance.

Biofilms in Action: Eco-Friendly Farming Innovations

The applications of biofilms in agriculture are vast and varied. Their unique properties make them effective as biofertilizers, bioremediators, stress mitigators, and biocontrol agents. Here are some of the key ways they are revolutionizing farming:

1. Biofertilizers for Sustainable Growth

Biofilms are highly effective as biofertilizers, enhancing root colonization and nutrient absorption. Unlike conventional fertilizers, biofilm-based biofertilizers (BFBFs) are resilient under stress conditions and reduce the need for synthetic inputs. In Sri Lanka, biofilm biofertilizers have cut down chemical fertilizer use by 50% while maintaining or even increasing yields in rice and vegetable cultivation. By producing growth hormones like indole-3-acetic acid (IAA) and gibberellins, biofilms stimulate faster root and shoot growth. They also improve soil aggregation, allowing plants to better access nutrients and water. This makes them a game-changer in combating soil fertility loss and food insecurity.

2. Bioremediation: Cleaning Up Contaminated Soils

Biofilms excel at absorbing and breaking down pollutants, making them powerful tools for soil and water bioremediation. They can immobilize heavy metals like chromium, lead, and cadmium, reducing their toxicity and improving soil health. Specific microbial strains, such as *Pseudomonas aeruginosa* and *Trichoderma harzianum*, have demonstrated significant potential in detoxifying contaminated environments. For example, biofilms of *Deinococcus radiodurans* have shown remarkable efficiency in removing uranium from contaminated water, highlighting their utility in addressing industrial waste challenges. These capabilities position biofilms as eco-friendly alternatives to conventional remediation methods, which are often costly and environmentally damaging.

3. Mitigating Stress for Resilient Crops

Drought, salinity, and other environmental stresses are major challenges for agriculture. Biofilms help crops withstand these adversities by improving root architecture, stabilizing soil, and optimizing water use. Studies on tomato plants have shown that biofilm-producing microbes enhance antioxidant activity and reduce tissue damage under water-stressed conditions. Halotolerant bacteria like *Bacillus licheniformis* form biofilms that improve plant growth in saline soils. They enhance nutrient uptake while minimizing the absorption of harmful salts, enabling crops to thrive in marginal lands

4. Natural Biocontrol Agents

Biofilms are also effective in suppressing plant pathogens and pests. By producing antimicrobial compounds and competing for resources, they inhibit the growth of harmful organisms. For instance, biofilms formed by *Bacillus* species protect plants from foliar diseases by forming a defensive layer on the plant surface. Certain biofilms also disrupt the communication systems of pathogens, known as quorum sensing, which is crucial for their virulence. This unique ability makes biofilms a sustainable alternative to chemical pesticides, reducing environmental harm while ensuring crop protection.

Challenges and Future Directions

While the potential of biofilms is undeniable, there are hurdles to their widespread adoption. High production costs and competition with native soil microbes can limit their effectiveness. Additionally, environmental variability poses challenges to the consistent performance of biofilms across different regions and crops. Research is now focusing on genetic engineering and strain selection to develop biofilms that are more efficient and adaptable. Advances in application techniques, such as seed coatings and soil inoculants, are also being explored to make biofilm technology more accessible to farmers. Collaboration between scientists, policymakers, and the agricultural industry will be crucial to overcoming these challenges. By investing in research and creating supportive regulatory frameworks, biofilms can transition from promising innovations to mainstream agricultural solutions.

A Greener Tomorrow with Microbial Biofilms

The integration of microbial biofilms into farming practices offers a sustainable path forward. They hold the key to regenerating soil health, reducing chemical inputs, and building climate-resilient agriculture. With their ability to address multiple challenges simultaneously—



soil degradation, pollution, and food security—biofilms represent a transformative tool for the future. As we face the global challenge of feeding a growing population while protecting the planet, microbial biofilms provide a beacon of hope. By embracing their potential, we can cultivate a greener, healthier, and more sustainable world for generations to come.



Volume: 05 Issue No: 12

WHITEFLY: A KEY VECTOR IN TOMATO: BIOLOGY, VIRUS TRANSMISSION, AND CONTROL STRATEGIES

Article ID: AG-VO5-I12-88

M. Naveen^{1*}, K. Naveena¹, V. Karthik¹, P.S. Shanmugam¹, M. Murugan¹ and M. Shanthi²

¹Department of Agricultural Entomology, Tamil Nadu Agricultural University,
Coimbatore - 641 003

²Centre for Plant Protection Studies, Tamil Nadu Agricultural University,
Coimbatore - 641 003, Tamil Nadu, India

*Corresponding Author Email ID: naveenm1696@gmail.com

Abstract

Whitefly (*Bemisia tabaci* Gennadius) is a highly polyphagous and invasive pest that poses a major threat to tomato (*Solanum lycopersicum* L.) cultivation worldwide, particularly in the tropical and subtropical regions. Its impact is twofold: direct damage through phloem feeding and indirect yet more severe damage as a vector of over 100 plant viruses, primarily begomoviruses. Among these, Tomato Leaf Curl Disease (TLCD), caused by a complex of begomoviruses, significantly reduces the yield and can lead to total crop failure. *B. tabaci* is a cryptic species complex comprising at least 46 genetic groups (biotypes), each differing in host preference, virus transmission efficiency, insecticide resistance, and endosymbiont composition. The biology and ecology of whitefly, along with its adaptability and virus-vectoring capabilities, are further influenced by environmental factors such as climate change. Effective management of whiteflies and TLCD requires an integrated pest management (IPM) approach that combines cultural practices, host resistance, biological control agents, physical barriers, and the judicious use of insecticides. This review focuses on the entomological aspects of *B. tabaci*, its role as a vector in tomato virus epidemics, and current strategies for sustainable and effective whitefly management.

Key words: *Bemisia tabaci*, tomato, begomovirus, virus transmission, integrated pest management

Intorduction

Tomato (*Solanum lycopersicum* L.) stands as one of the world's most extensively grown vegetable crops, producing about 186 million metric tons globally each year. India plays a major contributor in the tomato market, accounting for 11% of the global supply by harvesting 21.32 million metric tons from 871,000 hectares. Tomatoes are recognized as "functional foods" because of the presence of health-promoting bioactive compounds, including carotenoids, such as lycopene and β -carotene, and hydroxycinnamic acids, such as caffeic and chlorogenic acids, along with polyphenols, vitamins, and flavonoids, specifically quercetin, rutin, naringenin, and chalcone (Abubakar *et al.*, 2022). However, tomato cultivation is challenged by a range of biotic and abiotic stresses, with whiteflies being a prominent threat.

Biology and species complexity of whitefly:

Whiteflies, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), are a highly adaptable and polyphagous pest that infests over 700 plant species worldwide. They originated in southern Asia, but have now spread globally, with the highest prevalence in tropical regions, excluding Antarctica. In tropical and subtropical zones, it has emerged as a major crop protection issue for tomatoes. Female whiteflies lay approximately 150 stalked pear-shaped eggs on the underside of the leaves. The eggs hatch within 5–10 days, releasing mobile, scale-like nymphs that settle to feed and progress through second-, third-, and fourth-instar nymphs. The fourth instar nymphs are yellowish-white and are characterized by prominent red eyes visible through the body wall. This stage is commonly referred to as the "pupal" or "red-eyed nymph" stage, which further forms a puparium. Young adults emerge from puparia through T-shaped slit. Adults are covered with a white waxy bloom. The entire life cycle, from egg to adult, takes 18–28 days during warm weather and stretches to 30–48 days during winter (Perring *et al.*, 2018).

Generally, *B. tabaci* is a cryptic species complex comprising 46 biotypes globally, each exhibiting unique attributes like host range, dispersal, reproduction, endosymbiont composition, insecticide resistance, and efficiency in transmitting plant viruses. The distribution of *B. tabaci* biotypes in India revealed distinct patterns: Asia I and Asia II-1 dominated the central and northern regions, while Asia I, II-1, and II-5 are important in the northeast, and Asia I, II-5, and II-8 prevail in the south (Naveen *et al.*, 2025). Recent trends show that MEAM-1 (B biotype) multiplies rapidly with climate change, outcompeting others and further increasing the incidence of whitefly-transmitted plant viruses.

Whitefly transmitted begomoviruses affecting tomatoes in India:

Whiteflies damage tomato crops through the direct feeding of plant sap from nutrients and indirectly by transmitting plant viruses while feeding. Whiteflies transmit nearly 100 plant viruses belonging to five genera: *Begomovirus*, *Ipomovirus*, *Crinivirus*, *Carlavirus*, and *Torradovirus*. Begomoviruses are the most destructive group, causing tomato leaf curl disease (TLCD). They are grouped under the family *Geminiviridae*, the largest family of plant DNA viruses comprising more than 450 viruses. These viruses contain circular single-stranded DNA (ssDNA) genomes of approximately 2.7 kb and are characterized by distinctive twinned quasi-icosahedral virions, which range in size from 18 to 38 nm in diameter. Begomoviruses predominantly infect dicotyledonous plants, and their genomes can be either monopartite (consisting of DNA-A) or bipartite (comprising DNA-A and DNA-B) (Riley and Srinivasan, 2019).

Several begomoviruses have been reported to infect tomato crops in India. These include Tomato leaf curl New Delhi virus (ToLCNDV), Tomato leaf curl Bangalore virus (ToLCBaV), Tomato leaf curl Karnataka virus (ToLCKaV), Tomato leaf curl Kerala virus (ToLCKeV), Tomato leaf curl Patna virus (ToLCPaV), Tomato leaf curl Rajasthan virus (ToLCRaV), Tomato leaf curl Pune virus (ToLCPuV), Tomato leaf curl Joydebpur virus (ToLCJV), Tomato leaf curl Gandhinagar virus (ToLCGanV), Tomato leaf curl Gujarat virus (ToLCGUV), Tomato leaf curl Palampur virus (ToLCPaV), and Tomato leaf curl virus (ToLCV). Additionally, other begomoviruses such as Chilli leaf curl virus (ChiLCV), Mungbean yellow mosaic India virus (MYMIV), Croton yellow vein mosaic virus (CYVMV), Papaya leaf curl virus (PaLCuV), Pepper leaf curl Bangladesh virus (PepLCBV), Ageratum enation virus (AEV), Tobacco curly shoot virus (TbCSV), Tomato enation leaf curl virus (ToELCV), and Tomato severe leaf curl virus (ToSLCV) have also been associated with tomato infections in various regions of the country (Naveen *et al.*, 2025).

Feeding damage and virus transmission mechanism of whiteflies:

Whitefly feeding typically occurs on the underside of leaves, where insects extract large quantities of plant sap, leading to significant weakening of the plant. This feeding activity results in chlorotic spots, yellowing, downward curling, and drying of leaves. In cases of heavy infestation, whiteflies excrete honeydew, which promotes the growth of sooty mold on leaf surfaces. During feeding, whiteflies can acquire plant viruses by ingesting sap from the phloem

tissues of the infected plants. The insect must feed on an infected plant for at least 15 minutes to acquire the virus. For transmission to occur, the whitefly must then feed on a healthy host for approximately 15 to 30 minutes (Shivalingaswamy *et al.*, 2022).

Symptoms of tomato leaf curl disease and factors influencing its severity:

Tomato Leaf Curl Disease (TLCD) presents a wide range of characteristic symptoms, including upward or downward leaf curling, crinkling, puckering, vein clearing and thickening, yellow mottling, reduced leaf area, and severe leaf distortion. Infected plants commonly exhibit stunted growth, shortened internodes, flower drop, and poor fruit set. As the disease progresses, fruit production becomes severely impaired, often leading to complete crop failure (Smith *et al.*, 2019).

The severity of TLCD is further intensified by frequent genetic recombination events among begomoviruses, along with the high genetic variability among *B. tabaci* biotypes, which together enhance viral virulence and transmission efficiency. In addition, climate change has accelerated the spread and intensity of pest and disease outbreaks, especially in tropical regions, by altering pest behavior and ecological dynamics. Increasing reliance on high-input precision farming practices has also influenced pest populations, further aggravating their impact on crop health and productivity.

Management strategies for whitefly and Tomato leaf curl disease (TLCD):

The development of eco-friendly integrated pest management (IPM) strategies focuses on minimizing insecticide dependence and restoring the natural ecological balance involving predators, parasitoids, and microbial agents. An effective IPM approach for managing whiteflies involves adopting sound cultural practices, such as maintaining host-free periods, preserving beneficial natural enemies, regularly monitoring fields for early signs of infestation, and applying chemical pesticides only when necessary (Srinivasan, 2010; Smith *et al.*, 2019).

Cultural Control

- Uproot and destroy infected plants showing leaf curl symptoms to prevent further spread.
- Remove alternate weed hosts, especially *Abutilon indicum*, which serves as breeding sites for whiteflies and virus reservoirs.
- Practice judicious use of nitrogen and irrigation to avoid creating lush growth that attracts whiteflies.
- Adopt host-free periods between cropping seasons to break the whitefly-virus cycle.

- Grow fast-growing border crops like maize, sorghum, or pearl millet to act as physical barriers and reduce whitefly entry.

Physical and mechanical control

- Install yellow sticky traps at 12/hectare at canopy level to monitor the incidence of whiteflies.
- Use reflective (silver coloured) polyethylene mulches on planting beds to repel adult whiteflies and delay infestation by 4–6 weeks.
- Metalized mulches have been shown to reduce whitefly entry by as much as 90%.
- In protected cultivation, install insect-proof screens (10–20 micron mesh) in polyhouses to physically exclude whiteflies while allowing natural enemies to move freely.

Host plant resistance

- Promote the use of new crop varieties that exhibit increased tolerance to whiteflies and the viruses they transmit.

Biological control

- Encourage natural enemies such as green lacewings (*Chrysoperla zastrowi sillemi*), ladybird beetles, hoverflies, damsel bugs, mirid bugs, spiders, ground beetles, and small birds by maintaining year-round habitats, such as perennial plant borders.
- In greenhouses, release green lacewing at 10/m² to manage whitefly populations. It takes approximately eight weeks to establish an effective predator population. After release, restrict the use of broad-spectrum insecticides to protect these beneficial insects.
- Foliar spray of *Beauveria bassiana* and *Metarhizium anisopliae* (1X10⁸ CFU/gm) @ 1-2 kg/ha.

Botanical and organic measures

- Spray azadirachtin 0.15% EC at 2.5–5.0 l/ha along with a sticker (0.5 ml/l) for effective whitefly suppression.
- Apply fish oil rosin soap at 25 g/l along with a wetting agent to deter whiteflies.

Chemical control

- Use insecticides only when necessary and rotate active ingredients to prevent resistance.
- Recommended foliar sprays:
 - Thiamethoxam 25% WG – 200 g/ha

- Dimethoate 30 % EC – 990 ml/ha
- Imidacloprid 17.8 SL – 150 – 175 ml/ha
- Spiromesifen 22.9 SC – 625 ml/ha
- Cyantraniliprole 10.26 OD – 900 ml/ha

If required second spray may be given after 15 days.

References

- Abubakar, M., Koul, B., Chandrashekar, K., Raut, A. and Yadav, D. (2022). Whitefly (*Bemisia tabaci*) management (WFM) strategies for sustainable agriculture: A review. *Agriculture*, 12(9), 1317.
- Naveen, M., Shanmugam, P.S., Srinivasan, R., Shanthi, M., Murugan, M., Sivagnanapazham, K., Angappan, K., Oliva, R., Karthikeyan, G. and Boopathi, N.M., (2025). Recombination, phylogenetic insights and co-existence dynamics of begomoviruses and satellite DNAs: implications for tomato viral disease management. *Molecular Biology Reports*, 52(1), 390.
- Perring, T.M., Stansly, P.A., Liu, T.X., Smith, H.A. and Andreason, S.A., (2018). Whiteflies: Biology, ecology, and management. In: Wakil, W., Brust, G.E., and Perring, T.M. (Eds.) *Sustainable management of arthropod pests of tomato*. Academic Press. pp. 73-110.
- Riley, D.G. and Srinivasan, R. (2019). Integrated management of tomato yellow leaf curl virus and its whitefly vector in tomato. *Journal of economic entomology*, 112(4), 1526-1540.
- Shivalingaswamy, T.M., Udayakumar, A. and Mani, M., (2022). Pests and Their Management in Tomato. In: Mani, M. (Eds.) *Trends in Horticultural Entomology*. Springer Nature Singapore. pp. 959-970.
- Smith, H.A., Stansly, P.A., Seal, D.R., McAvoy, E., Polston, J.E., Gilreath, P.R. and Schuster, D.J. (2019). Management of whiteflies, whitefly-vectored plant virus and insecticide resistance for tomato production in southern Florida. Document ENY-735. University of Florida Institute of Food and Agricultural Sciences, Gainesville, FL, 8 p.
- Srinivasan, R. (2010). Safer tomato production methods: A field guide for soil fertility and pest management, AVRDC - The World Vegetable Center, Shanhua, Taiwan. AVRDC Publication No.10-740. 97 p.

Volume: 05 Issue No: 12

THE BATTLE UNDERGROUND: SOIL HEALTH AS A KEY DETERMINANT IN SUPPRESSING SOIL-BORNE PLANT PATHOGENS

Article ID: AG-VO5-I12-89

Deepika T¹ and Radha Krishnan G^{2*}

1-Ph.D. Scholar, Department of Plant Pathology, Faculty of Agriculture, Annamalai Univeristy, Chidambaram-608002

2- Junior Project Fellow, Division of Genetics and Tree Breeding, ICFRE-Institute of Forest Genetics and Tree Breeding, Coimbatore-641002, Tamil Nadu, India

*Corresponding Author Email ID: radhakrishvpm@gmail.com

Introduction

Soil serves as the primary interface between plants and their environment, functioning as both a physical substrate and a complex biological system essential for agricultural productivity. Beneath the crop canopy exists a dynamic soil microbiome governing key processes such as nutrient cycling, root development and disease suppression. Despite its importance, the biological intricacy of soil ecosystems remains underrecognized in conventional agricultural management. Soil-borne pathogens, including *Sclerotium rolfsii*, *Rhizoctonia solani*, *Fusarium oxysporum*, *Pythium* species and root-knot nematodes, continue to inflict substantial yield losses across major crops. Emerging research underscores that soil health characterized by high organic matter content, microbial diversity and balanced physical structure is pivotal in enhancing natural disease suppression and sustaining long-term crop resilience.

Soil-Borne Pathogens: Persistent and Destructive

Soil-borne pathogens constitute a major threat to global crop production due to their remarkable ability to survive and propagate under diverse environmental conditions. These organisms possess specialized survival structures such as sclerotia, chlamydospores, oospores and microsclerotia, which enable them to endure for extended periods in the absence of a host (Agrios, 2005). Prominent examples include *Sclerotium rolfsii*, responsible for stem rot in groundnut, vegetables, and legumes; *Rhizoctonia solani*, which causes damping-off and sheath

blight in cereals; and *Fusarium oxysporum* formaespeciales, the causal agent of vascular wilts in numerous horticultural crops. Additionally, species of *Pythium* and *Phytophthora* are major contributors to root rots in both nursery and field conditions, while root-knot nematodes (*Meloidogyne* spp.) induce root galling and frequently predispose plants to secondary fungal infections. Under favorable conditions, especially in monocropping systems with degraded soil structure and low biodiversity, yield losses from these pathogens can exceed 50 percent (Gomez Exposito et al., 2017). These high losses highlight the importance of integrated soil health management and biological control strategies to mitigate soil-borne diseases and sustain agricultural productivity.

Soil Health: A Natural Defense System

Healthy soils function as a biologically active defense network, mitigating the impact of soil-borne pathogens through diverse ecological and biochemical processes. The interplay between microbial communities, organic matter dynamics and soil structure collectively governs the suppressive capacity of soils and their resilience to disease outbreaks.

1. Microbial Antagonism and Competition

Soils with high microbial diversity support complex interactions among bacteria, fungi and actinomycetes that limit pathogen proliferation through niche competition, antibiosis and parasitism. Species of *Trichoderma* and *Bacillus* are particularly well-studied for their antagonistic properties, producing a range of bioactive compounds including antibiotics, volatile organic compounds (VOCs) and hydrolytic enzymes such as chitinases and glucanases (Harman et al., 2006; Ongena & Jacques, 2008).

2. Induced Systemic Resistance (ISR) in Plants

Beneficial rhizobacteria, notably *Pseudomonas fluorescens* and *Bacillus subtilis*, play a crucial role in enhancing plant immune responses through induced systemic resistance (ISR). These microorganisms activate defense signaling pathways regulated by jasmonic acid and ethylene, thereby reducing plant susceptibility to a broad spectrum of pathogens (Pieterse et al., 2014).

3. Soil Organic Matter and Structural Integrity

The accumulation of soil organic matter enhances microbial biomass, improves aggregation and promotes stable pore networks that facilitate gas exchange and water infiltration.

Such physical and biological improvements create an environment less favorable for moisture-dependent or anaerobic pathogens, including *Pythium* species (Bonanomi et al., 2010).

4.Disease-Suppressive Soils

Long-term ecological management practices such as organic amendments, diverse crop rotations, and minimized chemical dependency can lead to the development of disease-suppressive soils. In these systems, pathogen establishment is restricted by elevated microbial activity, functional redundancy, and enhanced nutrient cycling efficiency (Weller et al., 2002). These soils exemplify the self-regulating capacity of biologically balanced agroecosystems.

Case Studies Illustrating Soil Health–Disease Relationships

Real-world examples clearly demonstrate the link between soil health and the suppression of destructive soil-borne diseases. In groundnut cultivation, fields enriched with compost or microbial consortia consistently show reduced incidence of stem rot caused by *Sclerotium rolfsii*. The improvement is attributed to enhanced soil structure and the proliferation of antagonistic microbial populations that naturally inhibit the pathogen.

In the case of *Fusarium* wilt, soils containing abundant populations of non-pathogenic *Fusarium* species can suppress disease through competitive exclusion, a mechanism effectively documented in crops such as tomato and banana (Larkin & Fravel, 1999).

Vegetable nurseries affected by damping-off also benefit from improved soil health practices. The combination of solarization and organic amendments significantly lowers disease occurrence by reducing pathogen inoculum during heating and encouraging recolonization by beneficial microbes after treatment (Stapleton & DeVay, 1986). Collectively, these cases highlight how enhancing soil biological activity and structure can foster natural disease suppression and improve crop resilience under diverse farming conditions.

Toward Sustainable Soil-Borne Disease Management

Sustainable management of soil-borne diseases requires an integrated approach that enhances soil biological function and promotes ecological balance. Recent advancements in soil microbiology and agroecology emphasize the need for diversified management strategies that strengthen the soil's innate disease-suppressive capacity.

1.Integration of Organic Amendments

Application of organic inputs such as compost, green manures and vermicompost enhances microbial activity, enriches carbon pools and improves soil structure. These

amendments stimulate antagonistic microorganisms that suppress pathogens through mechanisms including antibiosis, parasitism, and competition for resources.

2. Microbial Consortia and Biocontrol Agents

The synergistic use of microbial consortia comprising *Bacillus*, *Trichoderma*, mycorrhizal fungi and plant growth-promoting rhizobacteria has shown considerable efficacy in pathogen suppression. These beneficial microbes complement each other's ecological functions, collectively enhancing nutrient cycling, root colonization and systemic resistance in plants.

3. Crop Rotation and Intercropping

Incorporating non-host crops and intercropping with diverse species reduces the buildup of specific pathogen propagules and fosters a more balanced microbial community. Such strategies contribute to the restoration of soil ecological equilibrium and reduce reliance on chemical control measures.

4. Minimized Chemical Disturbance

Heavy and frequent application of fungicides and synthetic fertilizers can disrupt beneficial microbial networks, creating ecological niches that favor opportunistic pathogens. Implementation of precision nutrient management and reduced chemical inputs supports the recovery of beneficial microbiota and maintains soil health.

5. Conservation Agriculture

Practices such as reduced tillage, cover cropping, and residue retention play a central role in stabilizing soil aggregates, conserving organic matter, and sustaining microbial diversity. These systems promote long-term resilience against soil-borne diseases by enhancing the biological and structural integrity of soil ecosystems.

Conclusion

The dynamic relationship between soil health and soil-borne pathogens represents a critical frontier in contemporary plant pathology and sustainable agriculture. As global food systems face increasing stress from climate variability, land degradation, and pathogen evolution, the restoration of soil health emerges as a foundational solution. Future innovations in soil microbiome research, biological control technologies, and the development of naturally suppressive soils will be pivotal in achieving resilient, eco-efficient cropping systems for the future.

References

- Agrios, G. N. (2005). *Plant Pathology* (5th ed.). Academic Press.
- Bonanomi, G., Antignani, V., Capodilupo, M., & Scala, F. (2010). Identifying the characteristics of organic soil amendments that suppress soil-borne plant diseases. *Soil Biology and Biochemistry*, 42(2), 136–144.
- Gomez Exposito, R., de Bruijn, I., Postma, J., & Raaijmakers, J. M. (2017). Current insights into the role of rhizosphere bacteria in disease suppressive soils. *Frontiers in Microbiology*, 8, 2529.
- Harman, G. E., Howell, C. R., Viterbo, A., Chet, I., & Lorito, M. (2006). Trichoderma species—opportunistic, avirulent plant symbionts. *Nature Reviews Microbiology*, 4(1), 43–56.
- Larkin, R. P., & Fravel, D. R. (1999). Mechanisms of action and interactions of nonpathogenic *Fusarium oxysporum* and other biological control agents for suppression of Fusarium wilt of tomato. *Phytopathology*, 89(12), 1152–1160.
- Ongena, M., & Jacques, P. (2008). Bacillus lipopeptides: versatile weapons for plant disease biocontrol. *Trends in Microbiology*, 16(3), 115–125.
- Pieterse, C. M. J., Zamioudis, C., Berendsen, R. L., et al. (2014). Induced systemic resistance by beneficial microbes. *Annual Review of Phytopathology*, 52, 347–375.
- Stapleton, J. J., & DeVay, J. E. (1986). Soil solarization: a non-chemical approach for controlling plant pathogens and pests. *Crop Protection*, 5(3), 190–198.
- Weller, D. M., Raaijmakers, J. M., McSpadden Gardener, B. B., & Thomashow, L. S. (2002). Microbial populations responsible for specific soil suppressiveness to plant pathogens. *Annual Review of Phytopathology*, 40, 309–348.

Volume: 05 Issue No: 12

BREEDING FOR RESISTANCE TO ABIOTIC STRESSES: SECURING CROP PRODUCTIVITY IN A CHANGING CLIMATE

Article ID: AG-VO5-I12-90**G. Anusha***

Research Associate, Agricultural Research Station, Tandur, PJTAU, Telangana, India.

*Corresponding Author Email ID: anusha21129@gmail.com

Abstract

Abiotic stresses such as drought, salinity, extreme temperatures and nutrient imbalances are major constraints to global crop production, especially as climate change intensifies. Breeding for resistance to these stresses has become essential to ensure stable yields, protect farmer livelihoods and strengthen food security. Plant breeders use a combination of traditional selection, molecular markers, genomic tools, high-throughput phenotyping and genome editing to identify, transfer and enhance stress-tolerant traits in major crops. Stress-resilient varieties would help the farmers to manage prolonged dry spells, salt-affected soils, nutrient-poor land and unpredictable temperature fluctuations. Advances such as QTL mapping, genome sequencing and CRISPR-based precision editing have accelerated the development of climate-resilient crops. This popular article explores how breeders tackle the most important abiotic stresses such as drought, salinity, mineral deficiency and toxicity, heat and cold stresses to build resilient cropping systems. These innovations are vital for sustaining agriculture in an era of environmental uncertainty.

Keywords: Abiotic stress, drought tolerance, salinity resistance, climate resilience, crop breeding and genomic tools

Introduction

Breeding for resistance to abiotic stresses has become a central priority in modern crop improvement, driven by the accelerating impacts of climate change, land degradation and resource scarcity. Unlike biotic stresses caused by pests and diseases, abiotic stresses such as drought, salinity, extreme temperatures, nutrient imbalances and flooding arise from

environmental and climatic factors that are difficult to manage using conventional agronomic practices. These stresses severely restrict plant growth, disrupt physiological and metabolic processes and contribute to substantial yield losses across major cropping systems worldwide.

As global food demand continues to rise, the development of crop varieties that can maintain high productivity under stress-prone conditions is critical for ensuring food and nutritional security. Breeding for abiotic stress resistance involves understanding the complex genetic, biochemical and physiological mechanisms that enable plants to tolerate adverse environments. Advances in genomics, phenomics, molecular markers, genome editing and speed breeding have opened new avenues to identify resilient traits, accelerate breeding cycles and create climate-smart cultivars tailored for diverse agroecosystems (Reynolds and Langridge, 2016).

By integrating conventional breeding with modern biotechnological tools, researchers and plant breeders are now better equipped to develop crop varieties capable of withstanding environmental extremes. Such innovations are essential not only to stabilize yields but also to promote sustainable agriculture, enhance farmer livelihoods especially in rainfed and marginal areas and build resilient food systems for the future.

Genetic, biochemical and physiological mechanisms

Plants possess a highly intricate **genetic architecture** that governs their ability to perceive, respond to and adapt to abiotic stresses. Stress tolerance is rarely controlled by a single gene; instead, it involves clusters of **quantitative trait loci (QTLs)**, transcription factors and regulatory elements that coordinate a plant's response at the molecular level. Genes involved in stress-signaling pathways such as those associated with abscisic acid (ABA), ethylene or drought-responsive elements play critical roles in initiating defensive reactions when plants are exposed to heat, drought, salinity or nutrient imbalance. Modern genomic tools, including genome-wide association studies (GWAS), high-throughput sequencing and gene-editing approaches like CRISPR-Cas, allow the breeders to identify and manipulate these genetic components, significantly accelerating the development of stress-resilient cultivars (Wassmann, *et al.*, 2009).

Beyond genetics, plants deploy a suite of **biochemical defenses** to protect cellular structures and maintain metabolic balance under stress. When exposed to drought or salinity, for instance, plants synthesize osmoprotectants such as proline, glycine betaine and soluble sugars

that helps to maintain cell turgor. Antioxidant enzymes like superoxide dismutase, catalase and peroxidases scavenge reactive oxygen species (ROS), preventing oxidative damage to membranes, proteins and DNA. Stress also triggers the production of heat-shock proteins, dehydrins and late embryogenesis abundant (LEA) proteins, which function as molecular chaperones to stabilize proteins and preserve cellular homeostasis. These biochemical adjustments serve as a vital buffer against the cellular disruptions caused by environmental extremes (Bailey-Serres, *et al.*, 2019).

On the **physiological level**, stress-tolerant plants exhibit several adaptive mechanisms that allow them to maintain essential growth processes. Drought-resistant crops often possess deeper, more efficient root systems that enhance water acquisition, along with reduced stomatal conductance to minimize water loss. Salt-tolerant plants regulate ion uptake and compartmentalization, preventing toxic accumulation of sodium and chloride ions in sensitive tissues. Heat-tolerant varieties maintain membrane stability and protect the integrity of reproductive organs, ensuring successful pollination and grain set even at higher temperatures. These physiological traits, many of which are measurable through advanced phenotyping tools, form the basis for selecting and improving stress-adapted genotypes (Hirabayashi, *et al.*, 2021).

Mostly, these **genetic, biochemical and physiological pathways do not operate in isolation**; they are interconnected components of a complex stress-response network such as physiological changes like stomatal closure are regulated by biochemical signals such as ABA, which in turn are controlled by specific genes. This multi-layered integration allows plants to respond rapidly and efficiently to fluctuating environments. Understanding these interactions enables the breeders to identify key leverage points like whether genes, metabolic pathways or physiological traits that can be targeted to enhance stress resilience (Munns, *et al.*, 2016).

As climate change intensifies the frequency and severity of abiotic stresses, unraveling these mechanisms becomes increasingly critical for crop improvement. By integrating insights from molecular biology, biochemistry, physiology and modern breeding technologies, researchers can develop varieties capable of sustaining productivity in stress-prone environments. Such knowledge-driven breeding strategies are essential for building climate-resilient agricultural systems and securing future food supplies.

Advances in biotechnological tools

Genomics

Genomic advances have transformed the ability of plant breeders to understand and manipulate the genetic basis of abiotic stress resistance. High-throughput sequencing technologies such as whole-genome sequencing, RNA-seq and pangenomics have enabled the discovery of stress-responsive genes, transcription factors and quantitative trait loci (QTLs) associated with drought, salinity, heat, cold and nutrient stress tolerance. Genomic tools allow researchers to dissect complex polygenic traits and understand how plants perceive stress signals and activate adaptive pathways. **A notable example is the identification and deployment of the *Sub1A* gene in rice**, which enables plants to withstand prolonged flooding. Using genomic mapping and marker-assisted introgression, *Sub1A* was successfully incorporated into popular rice varieties like Swarna and IR64, leading to the release of **submergence-tolerant “Scuba Rice”** grown widely across South and Southeast Asia. Additionally, genomic selection has accelerated the development of drought-tolerant maize hybrids by CIMMYT, where genome-wide marker data are used to predict performance under water-limited environments. These tools collectively empower breeders to develop resilient cultivars with greater precision (Crossa, *et al.*, 2017 and Juliana, *et al.*, 2022).

Phenomics

Phenomics provides a powerful framework to characterize plant responses to abiotic stresses with unprecedented accuracy and scale. Advanced phenotyping platforms ranging from drone-based imaging and field sensors to automated greenhouse systems and root imaging technologies, capture dynamic physiological and morphological traits that reflect a plant's stress tolerance. Measurements such as canopy temperature, chlorophyll fluorescence, water-use efficiency, root architecture and growth rates can now be monitored non-destructively and in real time. **The Australian Plant Phenomics Facility (APPF)** is a leading example, where high-throughput phenotyping pipelines have enabled the identification of wheat genotypes with superior heat and drought tolerance by monitoring traits such as transpiration efficiency and early vigour. Similarly, root phenotyping using shovelomics and X-ray computed tomography has improved selection for deeper, more efficient root systems in drought-tolerant maize lines. Through such innovations, phenomics strengthens the link between genotype and phenotype, enhancing the selection of stress-resilient crop varieties (Panda and Sarkar, 2012)

Molecular Markers

Molecular markers play a central role in accelerating the breeding process for abiotic stress resistance. Marker-assisted selection (MAS) enables breeders to track desirable alleles for traits such as drought tolerance, salt exclusion, osmotic adjustment and heat resilience with high precision. Marker-based approaches are particularly valuable for polygenic traits influenced by complex environmental interactions. **One successful example is the development of salt-tolerant rice varieties using the *Saltol* QTL**, which controls sodium–potassium homeostasis during early seedling stages. By using SSR and SNP markers, the *Saltol* QTL was introgressed into popular varieties like IR64 and Vandana, leading to improved salinity tolerance. Similarly, **QTLs like *DTY1.1* and *DTY3.1* have been used to develop drought-tolerant rice** through marker-assisted breeding, significantly improving productivity under water stress. In maize, genomic selection has helped CIMMYT breeders develop drought-tolerant hybrids under the Drought Tolerant Maize for Africa (DTMA) initiative. These marker-based strategies greatly enhance accuracy and reduce breeding time (Cobb, *et al.* 2019 and Collins, *et al.*, 2008).

Genome Editing

Genome editing technologies, particularly CRISPR-Cas systems, have opened new horizons in engineering abiotic stress tolerance with precision and minimal linkage drag. Unlike conventional breeding, genome editing allows targeted modification of specific genes that regulate stress perception, signaling, ion transport, osmotic balance or antioxidant pathways. **A landmark example is the CRISPR-edited drought-tolerant maize developed by Corteva Agriscience**, created by editing regulatory regions of the *ARGOS8* gene to enhance drought resilience without affecting yield potential. In rice, CRISPR editing of genes like *OsRR22* has produced salt-tolerant lines, while editing *OsNAC045* and *OsNRT1.1B* has improved drought and nitrogen-use efficiency, respectively. In tomato, editing the promoter of *SlALMT9* has enhanced aluminum tolerance. These genome-edited crops demonstrate how precise genetic changes can significantly strengthen tolerance to abiotic stresses. As many gene-edited lines remain non-transgenic, their path to acceptance and commercialization is faster (Gao, 2021).

Speed Breeding

Speed breeding is an innovative approach that dramatically shortens the time required to develop new varieties by optimizing environmental conditions to accelerate plant growth and flowering. By controlling photoperiod, light intensity, temperature and nutrition, speed breeding

enables 4–6 generations per year for crops such as wheat, barley, chickpea and canola. **A major success story is the use of speed breeding in Australia and the UK to rapidly develop wheat lines with improved heat and drought tolerance**, achieving up to six generations per year. In chickpea, speed breeding facilitated the development of lines with enhanced drought tolerance by accelerating recombination and fixation of desired alleles. CIMMYT has also integrated speed breeding with genomic selection to rapidly cycle drought-tolerant wheat under heat-stress conditions. Combined with molecular tools, speed breeding enables quicker pyramiding of multiple abiotic stress–resilience traits, ensuring timely development of climate-smart cultivars for changing environments (Khush, 2013 and Voss-Fels, *et al.*, 2018).

Future Prospects

Future advancements in breeding for abiotic stress resistance will increasingly rely on the seamless integration of multi-omics technologies, artificial intelligence and precision phenotyping. The convergence of genomics, transcriptomics, proteomics, metabolomics and phenomics will provide a holistic understanding of stress response networks and enable breeders to identify key molecular switches controlling plant resilience. Machine learning–driven predictive breeding models will enhance trait dissection, optimize parental selection and accelerate the discovery of stress-tolerance genes. Genome editing is expected to become more refined through base editing, prime editing, and multiplex CRISPR techniques, enabling precise manipulation of complex polygenic traits without compromising yield potential. Additionally, advancements in speed breeding and controlled-environment agriculture will further shorten breeding cycles and facilitate rapid trait pyramiding. The future also holds promise for climate-smart breeding pipelines that incorporate real-time environmental data, allowing breeders to design varieties tailored to specific agroecological zones. Collectively, these innovations will strengthen global efforts to develop crop varieties capable of thriving under rising temperatures, irregular rainfall, salinity intrusion and other climate-driven stresses (Jaganathan, *et al.*, 2018).

Conclusion

Overall, the integration of genomics, phenomics, molecular markers, genome editing and speed breeding has revolutionized the development of crops resilient to abiotic stresses. These technologies have enhanced our ability to decipher complex stress-response mechanisms, identify superior alleles and accelerate the breeding cycle with unprecedented precision and efficiency. Successful examples such as *Sub1* rice for flooding tolerance, Saltol rice for salinity

resilience, drought-tolerant maize through genomic selection, CRISPR-edited stress-tolerant crops and speed-bred wheat lines demonstrate the transformative impact of modern breeding innovations. As climate change continues to pose significant challenges to global agriculture, leveraging these advanced tools will be critical for ensuring sustainable crop production, enhancing food security and building resilient agroecosystems. The future of abiotic stress breeding lies in interdisciplinary integration, data-driven decision-making and rapid trait development pipelines that together will shape the next generation of climate-smart cultivars.

References

- Bailey-Serres, J., Parker, J.E., Ainsworth, E.A., Oldroyd, G.E and Schroeder, J.I. 2019. Genetic strategies for improving crop yields. *Nature*. 575: 109–118.
- Crossa, J., Pérez-Rodríguez, P., Cuevas, J., Montesinos-López, O., Jarquín, D., Campos, G and Dreisigacker, S. 2017. Genomic selection in plant breeding. *Crop Science*. 57(3): 986–996.
- Cobb, J.N., Biswas, P.S and Platten, J.D. 2019. Back to the future: Revisiting MAS as a tool for modern plant breeding. *Theoretical and Applied Genetics*. 132: 647–667.
- Collins, N.C., Tardieu, F and Tuberosa, R. 2008. Quantitative trait loci and crop performance under abiotic stress. *Journal of Experimental Botany*. 59(2): 387–406.
- Gao, C. 2021. Genome engineering for crop improvement and future agriculture. *Cell*. 184(6): 1621–1635.
- Gosa, S.C., Lupo, Y and Moshelion, M. 2019. High-throughput phenotyping in plants. *Plant Science*. 282: 73–81.
- Hirabayashi, H., Sasaki, K., Kambe, T and Kajiya-Kanegae, H. 2021. Advances in rice breeding for abiotic stress tolerance. *Breeding Science*. 71: 3–14.
- Jaganathan, D., Ramasamy, K., Sellamuthu, G., Jayabalan, S and Venkataraman, G. 2018. CRISPR for crop improvement. *Plant Cell Reports*. 37: 1663–1673.
- Juliana, P., Singh, R.P., Braun, H.J., Huerta-Espino, J., Bhavani, S., Randhawa, M.S and Crossa, J. 2022. Genomic selection for wheat improvement. *Theoretical and Applied Genetics*. 135: 2765–2780.
- Khush, G.S. 2013. Strategies for increasing the yield potential of cereals. *Plant Breeding*. 132: 433–436.

- Munns, R., James, R.A and Gilliham, M. 2016. Salinity tolerance mechanisms in crops. *Annual Review of Plant Biology*. 67: 651–681.
- Panda, D and Sarkar, R.K. 2012. Flooding tolerance in rice. *Functional Plant Biology*. 39: 961–976.
- Reynolds, M.P and Langridge, P. 2016. Physiological breeding. *Journal of Experimental Botany*. 67(3): 601–618.
- Voss-Fels, K.P., Snowdon, R.J and Hickey, L.T. 2018. Speed breeding innovations. *Nature Biotechnology*. 36: 796–802.
- Wassmann, R., Jagadish, K.S., Heuer, S., Ismail, A., Redona, E., Serraj, R and Singh, R.K. 2009. Climate change and rice production. *Advances in Agronomy*. 101: 59–122.



THE FUTURE OF FOOD

Article ID: AG-VO5-I12-91**Madhupriyaa D¹ and Mohanapragash A.G^{1*}**

Department of Soil Science and Agricultural Chemistry,
Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

*Corresponding Author Email ID: mpd98ars@gmail.com

Introduction

India's economy is agriculture based where about 70% population is dependent on practicing it. It ranks second and shares 11.3% arable land of the world. It means that India has high potential to harness agricultural resources for the present and future food security. However, about 21.9% (2016) people are living below poverty line and similarly a large number of people are deprived or insecure of food. This situation is most critical in the rural areas. Innovation in the food and agriculture sector may include, for example, new types for raw material processing technology, packaging of products, and new food additives. Applying new solutions may reduce or prevent adverse changes caused by microorganisms, oxidation of food ingredients, and enzymatic and non-enzymatic reactions. Moreover, healthier and more nutritious food may be delivered as well as the food may taste better due to improvements in food composition, including organoleptic changes, and changes in the perception and pleasures from eating food. Also, crops may be improved in terms of reduced exposure to diseases and resistance to changing weather conditions.

New food technologies can also offer solutions to malnutrition. According to the WHO (World Health Organization) approximately 30% of the global population is malnourished. It is suggested that by 2020 the whole European Union will consume less food than China and India together.

The Future of Food is a 2004 American documentary film written and directed by Deborah Koons Garcia to describe an investigation into unlabeled, patented, genetically

engineered foods sold in grocery stores in the United States for the past decade. In addition to the US, there is a focus on Canada and Mexico.

2) PRINCIPLES AND THE FUTURE OF FOOD

At the Global Alliance for the Future of Food we believe in the urgency of transforming global food systems, and in the power of working together and with others to effect positive change. Our work is guided by a set of seven shared principles: renewability, resilience, equity, diversity, healthfulness, inclusion, and interconnectedness. These principles shape our vision of the future of food, express our values, and encompass the change we want to make.

THE FUTURE OF FOOD: WHAT WILL BE EATING IN 20 YEARS

The “Future of Food” concept began nearly 15 years ago, when **genetically modified foods (GMOs)** were introduced in the United States. Now, in 2018, the question of *what* and *how* will we be eating in the future is continuously evolving. As reported by CSIRO, Australia, food demand is expected to continue to increase by 14% per decade, meaning food production needs to be nearly double its current rate in order to keep up. So, what will we be eating in the next 20 years and how will we feed more than 10 billion people across the globe by 2050?

Here are five ingredient innovations that will represent the future of our food and, perhaps, enhance food security, help feed the world’s growing food demands, and promote a sustainable global food production.

3) HIGH PROTEINS CREATED FROM INSECTS:

Insects as food or **edible insects** are insect species used for human consumption, e.g., whole or as an ingredient in processed food products such as burger patties, pasta, or snacks. The cultural and biological process of eating insects (by humans as well as animals) is described as entomophagy, represents the future of food. In fact, it is already a common practice in Thailand, China, Brazil, Mexico, and some African countries. For food security purposes, insect farming is actually considered a sustainable way to provide an ecologically viable food source to the world’s population. Certain species of insects, typically crickets, grasshoppers, and mealworms, are becoming the talk of the town in the field of high-protein food products. The aim of this innovation is two-fold:

- Primarily tackle the war on malnutrition in under-developed countries.
- Significantly reduce the environmental impact of the meat-heavy western diet.

4) EDIBLE INSECTS

Frequently consumed insect species

Estimates of numbers of edible insect species consumed globally range from 1,000 to 2,000. These species include 235 butterflies and moths, 344 beetles, 313 ants, bees and wasps, 239 grasshoppers, crickets and cockroaches, 39 termites, and 20 dragonflies, as well as cicadas. Which species are consumed varies by region due to differences in environment, ecosystems, and climate.

The table below lists the top five insect orders consumed by humans worldwide, retrieved from *Edible Insects: Future Prospects for Food and Feed Security* by Arnold van Huis, Joost Van Itterbeeck, Harmke Klunder, Esther Mertens, Afton Halloran, Giulia Muir and Paul Vantomme.

Order of insect	Common name	Consumption rate worldwide by human population (%)
Coleoptera	Beetles	31
Lepidoptera	Butterflies, moths	18
Hymenoptera	Bees, wasps, ants	14
Orthoptera	Grasshoppers, locusts, crickets	13
Hemiptera	Cicadas, leafhoppers, plant hoppers	10

Edible insects for industrialized mass production

To increase consumer interest in Western markets such as Europe and North America, insects have been processed into a non-recognizable form, such as powders or flour. Academics as well as large-scale insect food producers such as *Entomofarms* in Canada, *Aspire Food Group* in the United States, *Protifarm* and *Protix* in the Netherlands, and *Bühler Group* in Switzerland, focus on four insects species suitable for human consumption as well as industrialized mass production:

Mealworms (*Tenebrio molitor*) as larvae,

Lesser mealworms (*Alphitobius diaperinus*) as larvae, mostly marketed under the term buffalo worms.

House cricket (*Acheta domesticus*)

European migratory locust (*Locusta migratoria*)



Freeze-dried mealworms as food



Buffalo worms as food (or ingredient)



House crickets as food



Migratory locusts as food

5) NUTRITIONAL PROFILE:

Insects are nutrient efficient compared to other meat sources. Insects such as crickets are a complete protein and contain a useful amount comparable with protein from soybeans, though less than in casein (found in foods such as cheese). They have dietary fiber and include mostly unsaturated fat and contain some vitamins, such as vitamin B12, riboflavin and vitamin A, and essential minerals.

Locusts contain between 8 and 20 milligrams of iron for every 100 grams of raw locust. Beef on the other hand contains roughly 6 milligrams of iron in the same amount of meat. Crickets as well are very efficient in terms of nutrients. For every **100 grams of substance crickets contain**

12.9 grams of protein, 121 calories, and 5.5 grams of fat. Beef contains more protein containing 23.5 grams in 100 grams of substance, but also has roughly 3 times the calories, and four times the amount of fat as crickets do in 100 grams. So, per 100 grams of substance, crickets contain only half the nutrients of beef, except for iron. High levels of iron are

implicated in bowel cancer and heart disease.

6) FARMING, PRODUCTION & PROCESSING:

Edible insects are raised as livestock in specialized insect farms. In North American as well as European countries such as the Netherlands or Belgium, insects are produced under strict food law and hygiene standard for human consumption.

Several variables apply, such as temperature, humidity, feed, water sources, housing, depending on the insect species. The insects are raised from eggs to larvae status (mealworms, lesser mealworms) or to their mature form (crickets, locusts), and then killed, in industrialized insect farms by lowering the temperature. After that the insects are freeze-dried and packed whole, or pulverized to insect powder (insect flour), to be processed in other food products such as bakery products, or snacks.

Aside from nutritional composition and digestibility, insects are also selected for ease of rearing by the producer. This includes susceptibility to disease, efficiency of feed conversion, developmental rate and generational turnover.

7) INSECT FOOD PRODUCTS

- **Insect fitness bars:** The following processed food products are produced by several producers in North America, Canada, and the EU:
- **Insect flour:** Pulverized, freeze-dried insects (e.g., cricket flour).
- **Insect burger:** Hamburger patties made from insect powder / insect flour (mainly from worms or from house cricket) and further ingredients. Protein bars containing insect powder (mostly house crickets).
- **Insect pasta:** Pasta made of wheat flour, fortified with insect flour (house crickets or mealworms).
- **Insect bread** (Finnish *Sirkkaleipä*): Bread baked with insect flour (mostly house crickets).
- **Insect snacks:** Crisps, flips or small snacks (*bites*) made with insect powder and other ingredients.
- Food and drink companies such as the Australian brewery Bentspoke Brewing Co and the South- African startup Gourmet Grubb even introduced **insect-based beer**, a milk alternative, as well as **insect ice cream**



Insect burger made by mealworms



Fusilli made of cricket flour



Insect snacks (bites) with cultivated cricket flour and oat

8) Allergen-free nuts

A typical example of an allergen-free nut is the gluten-free tiger nut. As showcased at the Ingredient Show 2018 in Birmingham, UK, Ani de la Prida, co-founder of The Tiger Nut Company, explained the functional benefits of tiger nuts, noting:

“Tipped to be the next gluten-free superfood, tiger nuts are high in fiber and can be used as an additive-free, minimally processed ingredient in gluten-free baking.”



Tiger nuts food trends

The tiger nut, or *Cyperus esculentus*, a crop of the sedge family or weed plant, is widespread in Southern Europe, Africa, and Madagascar, as well as the Middle East and Indian Subcontinent.

Resembling sweet almond-like tubers, they are well-known for their high nutritive value, especially high fiber content, oleic acid, vitamins C and E, and minerals like potassium and phosphorus.

Importantly, tiger nuts are mainly used for the production of milk, which is suitable for consumers who are intolerant to gluten (celiac disease) and lactose. This video highlights how this special nut can be used, such as in your favorite smoothies.

9) Plant-based meat substitutes

We are quickly realizing the impact meat production has on the global ecosystem and biodiversity. Are we moving towards a meat-free dinner plate? Well, the trend is increasing. The health-conscious generation is asking for more plant-based products on the market, with clean labeling. Some companies are progressively making foods that taste just like meat. Examples include:

Beyond Meat: This Los Angeles-based company made the first plant-based burger. Other products include plant-based sausages, soy and pea protein-based chicken strips, and pea protein-based beef crumble. **Fry Family:** This South Africa-based company, similar to Beyond Meat, has over 15 different plant-based meat substitutes.

Impossible Foods: This California-based startup has done the impossible and made a plant-based burger that actually sizzles and bleeds like a meat burger, as demonstrated in the video. The company's Impossible Burger recently became certified as Kosher.

All of these plant-based innovations will reduce the need to raise and slaughter cattle and other livestock for human consumption. This could go a long way towards reducing animal cruelty, as well as tackling the issue of climate change. Moving towards plant-based substitutes could result in 15 times less water utilization, a reduction in methane gas emission, and saving our beautiful rainforests from further destruction. However, we should still consider the consumption of less processed foods and more real cooking, with nutrient-dense foods, to prevent nutritional deficiencies.

Algae: Algae farming could represent a potential game-changer in the way we eat food. Abundantly produced in both marine and freshwater environments, algae is seen as a solution for the problem of food shortages. An agricultural practice that has already begun in Asia, algae can be used to feed both humans and animals and could become the world's biggest crop industry.

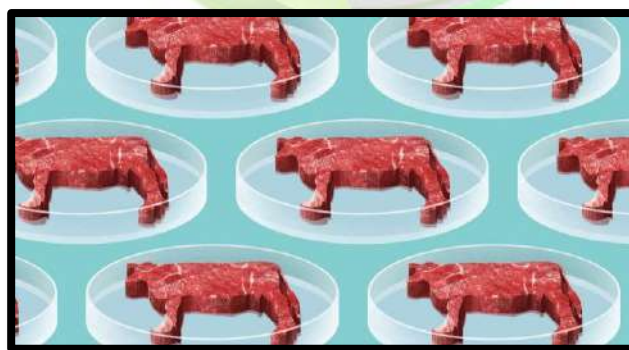
Terramino Foods: This start-up, based in San Francisco, developed a process to grow fungi that can be turned into a 'salmon' burger. It tastes, looks, and smells like the actual fish. Kimberlie Le, Co-

Founder and CEO of Terramino Foods, said that it is actually the addition of algae and other plant-based ingredients that make the burger taste similar to salmon. With the growing problem of overfishing, as well as the accumulation of pollutants such as mercury and microplastics in fish, Terramino's algae-based seafood could potentially serve as a sustainable seafood replacement.

10) Lab-grown meat

In the hope to curb global warming, while still providing meat for people who love their meat products, scientists have come up with the idea of producing synthetic meat grown in the lab. This scientific innovative technology began as early as 2013 and involves the culturing of ground beef from cow stem cells. Lab-grown meat, also known as cultured or *in-vitro* meat, apparently looks, cooks, smells, and tastes like ground beef. As published by Independent, the producer says, "The products could be on sale by the end of 2018." Conversations about this aspect have already begun by various associations.

For example, the United States Cattlemen's Association is arguing about the legal definition of 'beef' and 'meat'. Similarly, in Australia, the Food Standards Australia and New Zealand (FSANZ) Authority will ensure that a public health and safety assessment is performed on each different lab-grown meat product. Australians love their meat, no question about that. Hence, Australian regulators want to ascertain that the claims being made would not mislead their consumers and breach consumer laws. They mentioned: **"As a 'novel' food, lab-grown meat triggers requirements under our food standards codes."**



Culturing of ground beef

Conclusion

The rising global population and declining natural resources may soon force us to adopt newly invented foods as essential dietary options rather than choices of preference. Technological

innovations such as insect protein, lab-grown meat, algae products, and 3D-printed foods offer sustainable solutions to future food shortages. Although these foods may initially face cultural resistance, adapting to modern scientific advancements is necessary for survival. Instead of worrying about the past, society must embrace change to secure food and nutritional security. Accepting alternative foods will reduce environmental pressure and ensure a healthier future. Ultimately, the future of food depends on our willingness to transform traditional mindsets and adopt sustainable innovations.

References

- Alberti G (2001) Noncommunicable diseases: tomorrow's pandemics. *Bulletin of the World Health Organisation* 79: 907.
- Adhikari, L.; Tuladhar, S.; Hussain, A.; Aryal, K .2019. Traditional Food Crops Really 'Future Smart Foods. A Sustainability Perspective. *Sustainability*, 11, 5236.
- Backstrand JR (2002) The history and future of food fortification in the United States: a public health perspective. *Nutrition Reviews* 60: 15–26.
- Bertéus Forslund H, Torgerson JS, Sjöström L, Lindroos AK (2005) Snacking frequency in relation to energy intake and food choices in obese men and women compared to a reference population. *International Journal of Obesity (London)* 29: 711–719.
- Lange MC, Lemay DA and German JB (2007) Multi-ontology framework to guide agriculture Looking into the future of foods and health and food toward diet and health, *Journal of Science, Food, Agriculture* 87: 1427–1434.
- Rasul, G.; Saboor, A.; Tiwari, P.C.; Hussain, A.; Ghosh, N.; Chettri, G.B.2019. Food and nutrition security in the Hindu Kush Himalaya: Unique challenges and niche opportunities. In *The Hindu Kush Himalaya Assessment*; Wester, P., Mishra, A., Mukherji, A., Shrestha, A., Eds.; Springer: Cham, Switzerland, ; pp. 301–338
- Sloane EA (2006) Top ten functional food trends. *Food Technology* 60: 33.
- M. Klimczuk-Kochańska, A. Klimczuk. 2018. *Innovation in Food and Agriculture*, [in:] P.B. Thompson, D.M. Kaplan (eds.), *Encyclopedia of Food and Agricultural Ethics*, Second Edition, Springer, Dordrecht , pp. 1-7.

MORINGA – VALUE ADDED PRODUCTS

Article ID: AG-VO5-I12-92**¹A.Beulah and ¹*S.Maanchi**

Professor and Head, Department of Postharvest Technology, Horticultural College and
Research Institute, Periyakulam, TNAU, India

Senior Research Fellow, Department of Postharvest Technology, Horticultural College and
Research Institute, Periyakulam, TNAU, India

*Corresponding Author Email.ID: preethiee1996@gmail.com

Abstract

Moringa oleifera, known for its exceptional nutritional value, offers significant potential to address global malnutrition. However, its raw form faces limited acceptance, particularly in Tamil Nadu, India. Developing value-added Moringa products, such as leaf powder, energy bites, and tea, can enhance consumption and appeal. Establishing small-scale processing units in rural areas would not only improve nutritional intake but also create employment and promote sustainable livelihoods, providing a dual solution for community health and rural empowerment.

Key words: Miracle Tree, Nutritional benefits and Value added products

Introduction

Moringa (*Moringa oleifera* Lam.) is a nutritionally rich and highly valued plant cultivated widely in tropical and subtropical regions for food, medicinal and industrial purposes. Recognized as a “miracle tree,” its leaves and pods provide significantly higher levels of vitamins and minerals compared to many common foods, making it an important resource for combating malnutrition a key global challenge highlighted under the Millennium Development Goals. Despite India being the world’s leading producer and exporter of Moringa products, with a rapidly growing global market projected to exceed USD 6 billion by 2025, domestic utilization especially in Tamil Nadu, a major producing state remains limited due to low acceptance of its raw form, particularly among children. To enhance its consumption and fully realize its

economic and nutritional potential, there is a need to develop palatable and appealing value-added Moringa products. Establishing small-scale processing and value addition units in rural areas can improve nutritional intake while simultaneously creating employment, increasing rural incomes, and promoting sustainable livelihoods. Thus, value addition of Moringa serves as a dual solution for improving community health and strengthening rural empowerment.

Nutritional benefits of *Moringa olifera* of edible parts

Component/100 g Dry Weight	Leaves	Immature Fruit Pericarp	Seeds
Energy (kcal)	205–295.6	178.2	564.5
Protein (%)	19–27.1	17.2–19.3	32.9–38.3
Lipids (%)	4.7–5	0.4–1.3	30.8–44.8
Fiber (%)	7.9–19.2	22.6–46.8	4.9–15.9
Carbohydrates (%)	27–51.7	21–51	14.4–16
Calcium (mg)	1.875–2.076	12.5–29	76.9
Iron (mg)	27.8–38	2.3–5.3	13.7
Ascorbic Acid (vit c) (mg)	18.7–140	871	84.5
Chlorophyll (mg)	126.8	-	-

Development of value added products from *Moringa olifera*

Value added products	Raw materials	Product in use
Moringa leaf powder	Moringa leaves	Activating Role, Balancing Health, Cleansing role in the body(ABC)
Moringa Idly powder	Moringa leaves, blackgram, Redgram, Red chilli and Salt	General health
Moringa tea dip	Moringa leaves, lemon grass, lemon , Tulasi , Ginger and Mint	Nourishing and detoxifying nutrient rich super food , reduce body weight
Moringa leaf tablets	Moringa leaves	Vitality and Nutrient Supplement
Moringa energy	Moringa leaves, nuts , dry	Energy chocolate and nutrient

bites	ginger and country sugar	supplement
Moringa capsules	Moringa leaves	General health
Moringa energy Drops	Moringa leaves	Concentrated drops for good health
Bio Moringa Instant Soup	Moringa fresh Pods	ABC roles and General health
Moringa oil cake	Moringa Seeds	Water Purifier
Moringa Bio Booster	Different parts of moringa and other extracts	Plant growth promoter
Moringa Honey	Moringa flowers	Medicinal use
Moringa Chips	Tender Moringa pods	General health and protein supplement
Moringa Oil	Moringa seeds	Skin allergies, Moisturizing, Softness to skin
Moringa Gum Powder	Moringa Gum	Diuretic, Astringent, Fever, Dysentery , Asthma & Intestinal cancer



Fig 1: Different value added products of *Moringa olifera*

Conclusion

In conclusion, the value addition of Moringa leaves through products like Moringa powder, tea, and supplements offers significant nutritional benefits to both children and adults. Its rich profile of vitamins, minerals, and antioxidants makes it an excellent supplement for improving immune function, boosting energy and supporting overall health. For children, Moringa can help combat malnutrition, providing essential nutrients that are often lacking in their diet. For adults, it supports cardiovascular health, enhances skin health, and improves general well-being. Beyond its health benefits, Moringa cultivation and processing create valuable employment opportunities in rural areas, particularly through local farming, harvesting and small scale production of Moringa based products. This not only boosts local economies but also empowers rural communities by providing sustainable livelihoods and reducing poverty. By fostering both nutritional improvement and economic growth, Moringa represents a powerful tool for rural development, health improvement and community empowerment.

Reference

- Sagona, W. C. J., Paxie W. Chirwa, and Samson M. Sajidu. "The miracle mix of Moringa: Status of Moringa research and development in Malawi." *South African Journal of Botany* 129 (2020): 138-145.
- Fejér, J., Kron, I., Pellizzeri, V., Plúchtová, M., Eliašová, A., Campone, L., & Gruľová, D. (2019). First report on evaluation of basic nutritional and antioxidant properties of *Moringa oleifera* Lam. from Caribbean Island of Saint Lucia. *Plants*, 8(12), 537.

Volume: 05 Issue No: 12

SMART FISH PROCESSING: ROLE OF SENSORS AND AUTOMATION IN SEAFOOD QUALITY CONTROL

Article ID: AG-VO5-I12-93**B. Deepika* and P. Ganesan**

Department of Fish Processing Technology

Fisheries College and Research Institute, Thoothukudi – 628 008, Tamil Nadu, India

*Corresponding Author Email ID: deepikabaskar143@gmail.com

Abstract

Marine fish is highly perishable and demands strict quality control throughout processing. Traditional quality assessment methods rely heavily on human judgement, which can be subjective and inconsistent. Recent advancements in sensors, automation, and digital technologies have transformed marine processing into a more precise and efficient system. Smart fish processing integrates real-time monitoring, automated grading, and data-driven decision-making to ensure quality, safety, and reduced post-harvest losses. This popular article highlights the role of sensors and automation in modern seafood processing and their relevance to the Indian fisheries sector.

Keywords

Smart processing, sensors, automation, fish quality, seafood safety

Introduction

Fish quality is influenced by multiple factors such as handling, temperature, microbial activity, and storage conditions. Even minor lapses during processing can lead to spoilage, economic losses, and food safety concerns. In conventional processing plants, quality evaluation is often based on sensory inspection, which may vary among personnel. With increasing demand for safe, high-quality seafood and stricter export standards, the marine processing industry is moving towards smart and automated technologies.

Smart fish processing refers to the application of sensors, automation, and digital tools to monitor, control, and optimize processing operations. These technologies enhance accuracy, reduce human error, and improve overall efficiency.

Methods and Technological Approaches

To achieve smart fish processing, multiple technologies are integrated across different stages of the processing chain. These approaches focus on objective quality assessment, hygiene assurance, efficiency improvement, and traceability. The methods described below represent widely adopted and emerging practices in modern seafood processing plants.

Sensor-Based Quality Monitoring

Electronic nose and electronic tongue systems are used to detect spoilage-related volatile compounds, providing objective freshness assessment. Temperature and humidity sensors continuously monitor processing and storage environments, ensuring cold chain integrity.

Machine Vision Systems

High-resolution cameras and image analysis software are used for automated grading, size sorting, and defect detection in fish and shrimp. These systems improve uniformity and reduce processing time.

Automation and Robotics

Automated filleting, peeling, and packing systems reduce manual handling and contamination risks. Robotics also improve worker safety and productivity in high-volume processing units.

Data Integration and Traceability

Digital platforms integrate sensor data with processing records, enabling traceability from harvest to final product. Barcode systems, QR codes, and blockchain-based platforms allow tracking of raw material source, processing conditions, storage temperature, and distribution history. This is particularly important for export-oriented seafood industries, where transparency and compliance with international regulations are mandatory.

Benefits to Industry and Consumers

The integration of sensors and automation leads to reduced post-harvest losses, lower rejection rates in export consignments, and improved consistency in product quality. For consumers, smart processing ensures safer products with longer shelf life and reliable quality.

From an industry perspective, these technologies reduce labour dependency, improve productivity, and support data-driven decision-making.

Challenges and Future Prospects

Despite clear advantages, adoption of smart processing technologies faces challenges such as high initial investment, lack of skilled manpower, and limited awareness among small-scale processors. However, with the development of low-cost sensors, government-supported modernization schemes, and training initiatives, wider adoption is expected. In the future, artificial intelligence, predictive quality modelling, and Internet of Things (IoT)-based systems are likely to play a central role in marine processing automation.

Conclusion

Smart processing technologies are redefining the future of marine processing by ensuring consistent quality, enhanced food safety, and reduced losses. Although initial investment costs may be high, long-term benefits such as improved efficiency, compliance with international standards, reduced rejection rates, and improved consumer confidence make these technologies essential. Adoption of affordable sensor-based systems, gradual automation, and capacity-building programs can help integrate smart processing even in small and medium-scale units, thereby strengthening India's seafood sector and export competitiveness.

References

- FAO. (2020). *The State of World Fisheries and Aquaculture*. Food and Agriculture Organization of the United Nations.
- Olafsdottir, G., et al. (2017). Methods to evaluate fish freshness in research and industry. *Trends in Food Science & Technology*, 64, 42–53.
- Nunes, M. L., & Batista, I. (2019). Applications of sensors in seafood quality assessment. *Journal of Aquatic Food Product Technology*, 28(5), 467–481.
- Balaban, M. O., & Odabaşı, A. Z. (2016). Automation and robotics in fish processing. *Food Engineering Reviews*, 8, 1–14.
- Huss, H. H., Reilly, A., & Embarek, P. K. (2000). Prevention and control of hazards in seafood. *Food Control*, 11, 149–156.

BIODEGRADABLE PACKAGING FOR AGRI COMMODITIES

Article ID: AG-VO5-I12-94**Dr. R T Patil***

Ex Director, ICAR- Central Institute of Post–Harvest Engineering and Technology (CIPHET),
Ludhiana, Punjab, India

*Corresponding Author Email ID: ramabhau@gmail.com

Introduction

The packaging industry plays a crucial role in the agricultural sector, ensuring the safe transport, storage, and preservation of agricultural commodities. As global food supply chains become increasingly complex, effective packaging is essential to maintain product quality and minimize post-harvest losses. Traditional packaging materials, primarily made of plastics, have dominated the industry for decades due to their cost-effectiveness and versatility. However, these materials have raised significant environmental concerns due to their non-biodegradability, contributing to pollution and ecological degradation.

Recent studies indicate that over 400 million tons of plastic waste are produced globally each year, with India contributing around 3.5 million tons. The agricultural and food packaging sectors are significant contributors. In India alone, the Central Pollution Control Board (CPCB) reported that only 60% of plastic waste is collected, with a substantial portion polluting the environment. Globally, the recycling rate stands at just 9%, with much of the remaining waste ending up in landfills or waterways, causing severe ecological damage.

The detrimental impact of plastic waste on soil, waterways, and marine ecosystems has prompted a global call for sustainable alternatives. Biodegradable packaging offers a promising solution, as it can break down naturally into non-toxic components through microbial activity, thereby reducing the environmental footprint. Unlike traditional plastics, these materials decompose within months under composting conditions, contributing positively to soil health.

India's biodegradable packaging market is witnessing rapid growth, driven by increased awareness and supportive government policies, including bans on single-use plastics. Globally, the market for biodegradable packaging is expected to grow at a compound annual growth rate (CAGR) of 9.2%, reaching \$18 billion by 2027. The Indian market is projected to follow a similar trajectory, fueled by initiatives such as the Swachh Bharat Abhiyan and the extended producer responsibility (EPR) guidelines.

The adoption of biodegradable packaging not only aligns with environmental sustainability goals but also meets the growing consumer demand for eco-friendly products. This article explores the importance, materials, technologies, and benefits associated with biodegradable packaging for agricultural commodities, shedding light on how it can revolutionize the agricultural sector while safeguarding the environment.

The Need for Biodegradable Packaging

Environmental Impact of Conventional Packaging

The widespread use of plastic packaging in India has resulted in severe environmental issues, contributing to pollution, harm to wildlife, and degradation of natural ecosystems. India generates approximately 3.5 million tons of plastic waste annually, much of which is attributed to packaging for agricultural and food products. The Central Pollution Control Board (CPCB) estimates that around 40% of this waste remains uncollected, leading to environmental hazards. Non-biodegradable plastics take hundreds of years to decompose, accumulating in landfills and waterways. The Ganga and Yamuna rivers, among India's most vital water bodies, have become hotspots for plastic pollution, affecting aquatic life and water quality. Microplastics from packaging materials have been detected in soil, freshwater, and even food supplies, posing long-term health risks to humans and animals.

As these plastics break down, they release toxic substances, including heavy metals and chemical additives, which leach into the soil and water. This contamination depletes soil fertility, affecting agricultural productivity. Furthermore, the open burning of plastic waste, a common practice in rural areas, releases harmful greenhouse gases and dioxins, contributing to air pollution and climate change.

The environmental cost of conventional plastic packaging underscores the urgent need for sustainable alternatives. Government initiatives, such as the Plastic Waste Management Rules and bans on single-use plastics, aim to mitigate this crisis. Additionally, campaigns like Swachh

Bharat Abhiyan have raised awareness about the importance of reducing plastic waste.

Transitioning to biodegradable packaging can significantly alleviate these environmental challenges. Compostable materials derived from agricultural residues, such as bagasse and wheat straw, offer an eco-friendly solution while promoting the circular economy. By adopting sustainable packaging practices, India can reduce its environmental footprint, protect its natural resources, and pave the way for a greener, healthier future.

Materials for Biodegradable Packaging

Biodegradable packaging materials are derived from natural sources or designed to break down into harmless components. Key materials include:

Bioplastics

Bioplastics are rapidly gaining attention in India as a sustainable alternative to petroleum-based plastics, especially in response to rising environmental concerns. Derived from renewable resources like agricultural produce, bioplastics offer a great potential to reduce plastic pollution.

- **Polylactic Acid (PLA):** PLA is being increasingly used in India for packaging products like food containers, cups, and wraps. Sourced from corn or sugarcane, its biodegradability and compostability align with the government's initiatives to curb plastic waste. The growing adoption of sugarcane as a raw material, owing to its abundance in states like Uttar Pradesh, Maharashtra, and Tamil Nadu, makes PLA a viable solution for the food packaging industry. While the industry is still in its nascent stages, advancements in local production and government policies are helping PLA become more mainstream.
- **Polyhydroxyalkanoates (PHAs):** PHAs, which are biodegradable plastics produced by bacteria, hold great promise for India's packaging sector. These materials are produced by bacterial fermentation of agricultural residues and sugars, which are abundantly available across the country. With India's growing organic farming sector, PHAs could be derived from local resources like sugarcane molasses or agricultural residues, making them a sustainable alternative. They are also more likely to find applications in sectors such as food packaging and personal care products.

Starch-Based Films

India, with its agricultural strength, has the raw materials necessary to produce starch-based

biodegradable films. These films, made from starch extracted from crops like corn, potato, and tapioca, can serve as an eco-friendly packaging solution in the agricultural and food processing industries.

- **Agricultural Use:** In India, where plastic waste is a growing environmental issue, starch-based films are being explored for use in packaging fruits, vegetables, and grains. These films are biodegradable and provide a sustainable option for single-use agricultural packaging, which is commonly used in the transportation and sale of produce across local markets.
- **Sustainability in Rural Areas:** Since India is a major producer of crops like maize (corn) and potatoes, starch-based films present an opportunity to convert local agricultural waste into useful packaging materials. This could reduce reliance on imported plastic films, decrease agricultural waste, and create rural employment opportunities, further contributing to the circular economy.

Cellulose-Based Packaging

Cellulose, a biodegradable material derived from plant fibers, is gaining popularity in India due to its eco-friendly and compostable nature. With a vast and diverse agricultural base, India is well-placed to capitalize on cellulose-based packaging derived from sources such as wood, cotton, and even agricultural residues like wheat straw and bagasse.

- **Fresh Produce Packaging:** In India, fresh produce such as fruits and vegetables is often packaged in plastic. Cellulose-based packaging offers a sustainable alternative, especially for products that require breathable packaging to extend shelf life. Cellulose packaging is especially useful for high-value produce like apples, tomatoes, and leafy greens, ensuring they stay fresh during transportation and at retail outlets.
- **Composting Infrastructure:** The growing focus on waste management and composting in urban India, especially in cities like Bengaluru and Mumbai, could provide the necessary infrastructure to support the widespread adoption of cellulose-based packaging. These materials can be easily composted in organic waste bins, reducing landfill accumulation.

Edible Packaging

Edible packaging, made from natural materials such as proteins or polysaccharides, is an innovative solution that has caught the attention of Indian food manufacturers. It's especially relevant for high-value agricultural products like fresh fruits, dairy items, and snacks, which are often prone to spoilage and require protective packaging.

- **Food Industry Trends:** In India, where the processed food sector is rapidly expanding, edible packaging could become a unique selling point for premium food items. For example, edible wrappers made from rice, corn, or even seaweed can be used for packaged snacks or sweets like ladoos or fruit rolls, promoting sustainability while offering a novel consumer experience.
- **Regional Applications:** India's diverse food culture presents an opportunity for region-specific edible packaging. For instance, packaging made from traditional grains like rice or millets could be used for products such as idli or dosa mix, promoting local ingredients and reducing plastic waste. This trend could attract health-conscious and environmentally aware consumers.

Agricultural Waste-Based Materials

India produces a significant amount of agricultural waste that is often not utilized effectively. However, converting agricultural byproducts into packaging materials offers a sustainable and circular economy solution. Packaging derived from rice husks, wheat bran, coconut coir, and sugarcane bagasse is not only biodegradable but also contributes to waste reduction in the agricultural sector.

- **Rice Husks and Wheat Bran:** With India being one of the largest producers of rice and wheat globally, agricultural waste such as rice husks and wheat bran is abundantly available. Companies in India are exploring ways to convert these byproducts into packaging materials, including trays, containers, and bags. This also adds value to what would otherwise be discarded, improving the livelihoods of farmers and creating a new market for agricultural waste.
- **Coconut Coir:** In states like Kerala and Tamil Nadu, where coconut farming is prevalent, coconut coir is a significant byproduct. It is being explored for use in eco- friendly packaging

such as molded packaging products. Coconut coir is strong, durable, and compostable, making it ideal for the transportation of agricultural produce like coconuts and tender coconuts, while also addressing the issue of coir waste.

Biodegradable packaging materials offer a sustainable solution for the packaging needs of India's fast-growing agricultural sector. By leveraging its rich agricultural resources and the increasing focus on waste reduction, India can take significant strides toward reducing plastic pollution and promoting eco-friendly packaging alternatives. The integration of these materials into mainstream packaging will not only help reduce environmental impact but also create new markets and job opportunities, benefiting both the economy and the environment.

Technologies in Biodegradable Packaging

Extrusion Technology

Extrusion technology is one of the key methods for producing films, sheets, and various biodegradable packaging products. This technology involves forcing materials like bioplastics or biodegradable polymers through a mold to create films or sheets that can be used for various packaging applications.

- **Local Production Potential:** India's agricultural sector, which produces vast quantities of crops like corn, potatoes, and sugarcane, offers abundant raw materials for biodegradable films. For instance, starch-based films made from these materials can be produced through extrusion processes. Extrusion also enables the production of multi-layered films, providing the flexibility to incorporate natural biopolymers such as polylactic acid (PLA) for stronger, more durable packaging.
- **Agricultural Packaging:** Extruded films are highly suitable for packaging agricultural commodities like grains, fruits, and vegetables, which require lightweight yet durable packaging. With India's growing focus on reducing plastic waste, extrusion technology is poised to offer a sustainable alternative to traditional plastic packaging. For example, biodegradable packaging for fresh produce such as tomatoes, bananas, and onions could be produced through extrusion, supporting India's food processing and agricultural export industries.
- **Government Initiatives:** The Indian government's push towards sustainable practices, through initiatives like the 'Swachh Bharat Mission' and the ban on single-use

plastics, creates a favorable environment for the growth of extrusion technology. The adoption of extrusion for biodegradable packaging would align with these initiatives, reducing plastic pollution while promoting eco-friendly packaging solutions.

Injection Molding

Injection molding is widely used to produce rigid packaging components like trays, containers, and bottles. In the Indian context, this technology can be harnessed for the production of biodegradable packaging made from bioplastics, offering a cost-effective solution for manufacturers.

- **Suitability for Mass Production:** India's fast-growing retail and e-commerce sectors are driving the demand for mass-produced, standardized packaging solutions. Injection molding offers precision and scalability, enabling manufacturers to produce large volumes of rigid packaging items such as containers for ready-to-eat meals, fruit trays, and cosmetic containers. By utilizing bioplastics like PLA or PHA, Indian manufacturers can offer sustainable alternatives to traditional plastic packaging.
- **Sustainability in Food Packaging:** With food safety and hygiene becoming increasingly important in India, particularly in the context of packaged food and beverages, injection-molded packaging can play a key role in creating eco-friendly and safe alternatives. Injection-molded containers made from bioplastics can provide the same strength and durability as conventional plastics but with the added advantage of being biodegradable or compostable.
- **Industrial Growth in Tier 2 and Tier 3 Cities:** As India's small and medium-sized enterprises (SMEs) in manufacturing scale up, the adoption of injection molding for biodegradable packaging could become a driving force for local economic growth. This would also stimulate job creation in regions where plastic waste management is a concern, particularly in industrial hubs across Maharashtra, Gujarat, and Tamil Nadu.

Coating Techniques

Coating techniques are crucial for enhancing the performance of biodegradable packaging materials, particularly in protecting agricultural products from environmental factors like moisture and oxygen. These biodegradable coatings, made from natural ingredients such as plant-based oils, proteins, or starch, help extend the shelf life of perishable items.

- **Barrier Properties for Agricultural Products:** India, being one of the world's largest producers of fruits and vegetables, faces significant challenges related to post-harvest losses due to inadequate packaging. Coating techniques can provide a sustainable solution by enhancing the barrier properties of biodegradable materials used for wrapping or packaging fruits and vegetables. For example, biodegradable coatings can be applied to reduce moisture loss in fresh produce like mangoes, apples, and potatoes, extending their shelf life and reducing spoilage during transportation.
- **Eco-friendly Innovations:** In India, where agriculture is a key economic driver, there is a growing emphasis on reducing the environmental impact of farming operations. Biodegradable coatings made from local agricultural waste, such as rice bran or wheat germ, offer an eco-friendly solution. Coatings derived from such materials can be applied to paper or biodegradable films, making them suitable for use in packaging for products like spices, grains, and herbal medicines, thereby improving the sustainability of packaging.
- **Government and Research Support:** The Indian government's push towards promoting 'Make in India' initiatives, along with funding for agricultural innovation, has fostered research into biodegradable coating technologies. Several academic institutions and research centers in India, including those focused on food and agricultural sciences, are exploring the use of natural coatings to improve the sustainability of packaging materials.

Applications of Biodegradable Packaging Materials

Fresh Produce Packaging

Fresh produce, such as fruits and vegetables, is highly susceptible to spoilage due to environmental factors like moisture, oxygen, and temperature. In India, where a significant portion of agricultural produce is sold in local markets, biodegradable packaging can offer an effective solution to enhance shelf life and reduce waste.

- **Breathability and Moisture Regulation:** Biodegradable films made from materials like PLA (Polylactic Acid) or starch-based biopolymers are gaining traction in India's fresh produce market. These materials offer excellent breathability, ensuring that the packaged produce can "breathe" and preventing condensation that could lead to spoilage. This is particularly important in humid climates like those in Kerala, West Bengal, and the coastal regions,

where moisture regulation is crucial for maintaining product quality.

- **Reduction of Plastic Use:** In India, fresh produce is often sold in plastic bags or wrapped in plastic films, contributing to growing plastic waste in urban and rural areas. With increasing awareness about plastic pollution, biodegradable alternatives like plant-based films and trays are becoming a preferred choice for packaging. They provide an eco-friendly solution while aligning with government initiatives to reduce plastic usage, such as the ban on single-use plastics in several states.
- **Extended Shelf Life:** In a country where food wastage due to spoilage is a significant issue, biodegradable packaging helps reduce losses during transportation and storage. For instance, biodegradable trays used to pack mangoes or tomatoes ensure that the produce reaches local markets and export hubs in better condition, with reduced spoilage, especially during transit over long distances.

Grain and Pulses Packaging

Grains and pulses are staple foods in India, and the packaging materials used play a crucial role in their storage and transportation. With the country's vast agricultural production, biodegradable packaging offers a more sustainable way to manage these commodities, especially in light of India's goal to reduce plastic waste.

- **Eco-friendly Sacks and Pouches:** Traditionally, grains and pulses are stored in plastic bags or jute sacks. Biodegradable packaging solutions, such as those made from starch-based or cellulose materials, provide an eco-friendly alternative. These packaging materials are compostable, reducing the environmental impact associated with plastic bags, which take years to degrade in landfills.
- **Protection from Moisture and Pests:** One of the primary concerns in storing grains and pulses is their vulnerability to moisture and pest infestations. Biodegradable sacks or pouches with added moisture barriers and natural pest-repellent properties offer an effective solution to protect stored commodities. Materials like rice husks or bagasse can be used in the production of such packaging, which not only protects the grains but also utilizes agricultural waste, supporting a circular economy model.
- **Rural Economy and Waste Reduction:** The adoption of biodegradable packaging for grains and pulses

would benefit rural farmers by offering affordable and sustainable packaging solutions. In states like Punjab, Haryana, and Uttar Pradesh, where large-scale grain production takes place, biodegradable packaging could significantly reduce plastic use in the agricultural sector, contributing to cleaner rural landscapes and improved waste management.

Dairy Products Packaging

The dairy sector in India is one of the largest in the world, with products like milk, yogurt, and cheese being staples in most households. Biodegradable packaging plays a crucial role in preserving the quality of these products while reducing the environmental impact associated with conventional plastic packaging.

- **Bioplastics and Cellulose for Barrier Properties:** Dairy products require packaging materials that provide effective barriers to oxygen, moisture, and contaminants. Bioplastics, such as PLA, and cellulose-based films are emerging as ideal materials for this purpose in India. They are capable of providing the necessary freshness protection for products like milk pouches, yogurt containers, and cheese wraps, ensuring they stay fresh during storage and transportation.
- **Safety and Sustainability:** With increasing consumer awareness about health and sustainability, there is growing demand for dairy products packaged in biodegradable or recyclable materials. Indian consumers, especially in urban centers like Delhi, Mumbai, and Bengaluru, are increasingly seeking products that align with their eco-conscious values. Biodegradable packaging for dairy products thus not only provides functionality but also adds a premium appeal to the product, promoting sustainability in the food industry.
- **Regulatory Compliance and Safety Standards:** Biodegradable materials used for packaging dairy products must meet stringent food safety standards. Bioplastics like PLA and cellulose-based materials are certified for food contact and are increasingly being adopted by dairy brands in India, which are looking to align their packaging practices with international sustainability norms.

Meat and Poultry Packaging

Meat and poultry products are highly perishable and require packaging materials that can protect them from spoilage while ensuring food safety. Biodegradable packaging with enhanced oxygen and moisture barriers is especially suited for packaging perishable meat and poultry items in

India, where the consumption of non-vegetarian food is growing rapidly.

- **Oxygen and Moisture Barriers:** Biodegradable packaging materials such as PHA (Polyhydroxyalkanoates) and bioplastics are being used to package meat and poultry products, offering superior moisture and oxygen barrier properties. These properties are crucial for maintaining the freshness of meat products, reducing spoilage, and extending shelf life. In India, where the transportation and distribution of fresh meat can sometimes involve long distances, these packaging solutions are essential for ensuring product quality until it reaches consumers.
- **Sustainability in the Meat Industry:** India's growing meat and poultry industry is increasingly adopting sustainable packaging practices. With the government's focus on reducing plastic waste, biodegradable packaging offers a more environmentally responsible alternative to traditional plastic packaging, which is commonly used in the meat industry. By switching to biodegradable materials, Indian meat producers can reduce plastic pollution and appeal to the growing consumer base that values sustainability.
- **Regulatory Compliance and Safety:** Biodegradable packaging materials for meat and poultry must comply with food safety regulations to prevent contamination and ensure the hygiene of the product. Bioplastics and cellulose-based materials are approved for use in food-grade applications in India and are gaining popularity in meat and poultry packaging due to their biodegradability and safety for direct food contact.

Value-Added Agricultural Products

India's processed food sector is growing rapidly, with a rising demand for value-added agricultural products like snacks, sauces, juices, and beverages. The shift toward eco-friendly packaging for these products is being driven by consumer preferences for sustainable and recyclable packaging.

- **Biodegradable Packaging for Snacks and Beverages:** Value-added products such as packaged snacks, juices, and sauces are often sold in plastic packaging. However, with the increasing consumer demand for sustainable packaging solutions, biodegradable alternatives are gaining traction. Materials like PLA, cellulose, and starch-based films are being used to package products such as fruit juices, sauces, and ready-to-eat snacks, offering a premium, eco-

friendly solution.

- **Premium Appeal and Branding:** As Indian consumers become more environmentally conscious, biodegradable packaging adds value to processed agricultural products by enhancing their appeal. Brands in India are leveraging sustainable packaging to differentiate themselves in the competitive market, particularly in sectors like organic foods and beverages. The use of biodegradable packaging also allows companies to align their products with the "green" marketing strategies that resonate with eco-conscious consumers.
- **Circular Economy and Agricultural Waste Utilization:** The production of biodegradable packaging from agricultural waste, such as rice husks, wheat bran, and sugarcane bagasse, offers an opportunity to close the loop in the agricultural value chain. By using these byproducts to create packaging for value-added products, India's food processing industry can contribute to a circular economy model, where waste is minimized, and resources are used efficiently.

Benefits of Biodegradable Packaging

Environmental Benefits

India faces significant challenges related to plastic waste management, with plastic pollution becoming a major environmental issue, especially in urban centers like Delhi, Mumbai, and Bengaluru. Biodegradable packaging offers several key environmental benefits that align with India's sustainability goals:

- **Reduction of Landfill Waste:** Traditional plastic packaging takes hundreds of years to break down in landfills, contributing to long-term environmental degradation. In contrast, biodegradable packaging made from materials like bioplastics (PLA, PHA), starch-based films, and agricultural waste decomposes naturally, leaving no harmful residues. In India, where waste management infrastructure is often under strain, biodegradable packaging can significantly reduce the burden on landfills and waste processing facilities.
- **Minimizing Pollution:** In cities like Chennai, Kolkata, and Hyderabad, plastic waste is often found clogging drainage systems, waterways, and public spaces. Biodegradable packaging offers a sustainable alternative, as it decomposes without releasing harmful chemicals

into the environment. This is particularly important for protecting soil, water bodies, and public health from plastic waste pollution, which can take centuries to degrade.

- **Conservation of Natural Resources:** Biodegradable packaging, often made from renewable sources like corn starch, sugarcane, and agricultural byproducts, helps conserve natural resources. India is one of the largest agricultural producers in the world, and using agricultural waste (such as rice husks, wheat bran, or sugarcane bagasse) to create biodegradable packaging can reduce the need for petroleum-based plastics, which are energy-intensive and contribute to the depletion of fossil fuels.
- **Protection of Marine Life and Ecosystems:** Plastic waste in India's rivers, beaches, and oceans poses a serious threat to marine ecosystems. Cities like Mumbai and coastal areas like Goa and Kerala are impacted by plastic pollution. Biodegradable packaging, especially materials like PHAs, can decompose in marine environments, helping to protect marine life and reduce the threat to aquatic ecosystems. By shifting to biodegradable alternatives, India can play a pivotal role in mitigating the impact of plastic pollution on marine biodiversity.

Economic Advantages

The transition to biodegradable packaging presents several economic benefits, which are particularly relevant in the Indian context, where economic growth is closely tied to sustainability efforts:

- **Lower Long-term Disposal Costs:** India spends significant amounts on waste collection, sorting, and disposal, especially in major cities. By reducing reliance on plastic packaging and shifting to biodegradable alternatives, municipalities can lower long-term waste management expenses. Biodegradable packaging decomposes naturally, meaning fewer resources are needed for its disposal, which can ease the strain on urban waste management systems.
- **Creation of a Circular Economy:** In India, agricultural byproducts like sugarcane bagasse, rice husks, and wheat straw are often underutilized. By using these materials in biodegradable packaging production, a circular economy can be established, where agricultural waste is repurposed, reducing waste and creating economic value. This process can boost rural economies by creating new business opportunities in the agricultural waste-to-packaging sector.

- **New Revenue Streams through Composting and Recycling:** India's growing waste management sector presents an opportunity for businesses to capitalize on biodegradable packaging. Materials like starch-based films and bioplastics can be composted, creating organic compost for agricultural use. Additionally, biodegradable packaging materials can be recycled or repurposed in other industries, creating new revenue streams and job opportunities in regions like Maharashtra, Punjab, and Uttar Pradesh.
- **Export Potential:** As global demand for sustainable and eco-friendly packaging rises, India's burgeoning biodegradable packaging industry could tap into international markets. Indian manufacturers of biodegradable packaging can explore export opportunities to countries that are actively seeking sustainable alternatives to plastic, thus opening up new avenues for economic growth in this sector.

Challenges and Limitations of Biodegradable Packaging

Cost

One of the most significant barriers to the widespread adoption of biodegradable packaging in India is the higher cost compared to traditional plastic packaging. This price difference stems from several factors:

- **Higher Production Costs:** Biodegradable materials, especially those derived from agricultural byproducts or bioplastics like PLA (Polylactic Acid) and PHA (Polyhydroxyalkanoates), are often more expensive to produce. In India, where cost sensitivity is high, especially in industries like food packaging, the higher upfront cost can discourage businesses from switching to these alternatives. For instance, bioplastics require more sophisticated manufacturing processes, which adds to production costs.
- **Limited Raw Material Availability:** The raw materials required for biodegradable packaging, such as corn starch, sugarcane bagasse, or specific agricultural waste, may not be readily available in sufficient quantities or may require specialized supply chains. This scarcity adds to the overall cost, especially in regions where these resources are not locally sourced.
- **Economies of Scale and Technological Advancements:** While the cost of biodegradable materials is currently a barrier, India's large agricultural sector holds promise for reducing costs

through economies of scale. As the demand for biodegradable packaging grows and production technologies improve, the costs of raw materials and manufacturing are expected to decrease. Furthermore, government subsidies or incentives for sustainable practices may help bridge the initial cost gap and make biodegradable packaging more accessible to Indian businesses.

Performance Limitations

While biodegradable materials are gaining popularity, there are still challenges related to their performance, particularly in packaging applications where high durability is essential. Some of these limitations include:

- **Strength and Durability:** Biodegradable materials, especially those made from starch-based films or cellulose, may not offer the same level of strength and durability as traditional plastics. This can make them unsuitable for packaging heavier products or for use in high-stress environments, such as transportation of bulk agricultural products. For example, biodegradable bags may not be as strong as plastic bags for carrying heavy grains or pulses, especially in humid conditions.
- **Moisture and Barrier Properties:** India's diverse climatic conditions, ranging from humid coastal areas to dry desert regions, require packaging materials that can withstand moisture and maintain product integrity. While biodegradable films can offer some degree of moisture resistance, they may not always perform as well as conventional plastics in terms of moisture and oxygen barriers, making them less effective in preserving products like dairy, meat, or processed foods.
- **Shelf Life Concerns:** In the Indian agricultural context, where fresh produce is a significant portion of packaging applications, the shelf life of biodegradable packaging can sometimes be shorter compared to plastic alternatives. For instance, packaging materials that provide inadequate protection from moisture or contamination may lead to early spoilage of fruits, vegetables, and other perishable goods, especially in the humid conditions prevalent in regions like Kerala or coastal Tamil Nadu.
- **Research and Development:** However, ongoing research in India is addressing these performance challenges. With growing investments in sustainable

packaging solutions, Indian companies and research institutions are working towards improving the strength, durability, and barrier properties of biodegradable materials, making them more viable for a wider range of agricultural applications.

Future Trends and Innovations in Biodegradable Packaging

Advanced Biopolymers

The future of biodegradable packaging in India is closely tied to the development of advanced biopolymers, which promise to address many of the current limitations of biodegradable materials. Researchers in India are exploring various renewable sources to create high-performance biopolymers with improved properties:

- **Enhanced Strength and Durability:** One of the key challenges of biodegradable packaging in India is its strength and durability. Advanced biopolymers are being developed to address these weaknesses. By using plant-based resources such as lignocellulosic fibers (e.g., jute or cotton) or agricultural byproducts (e.g., sugarcane bagasse), researchers are working to improve the mechanical strength of bioplastics while maintaining their compostability. This would make biodegradable materials more suitable for a wider range of packaging applications, including heavier agricultural products like grains and vegetables that are common in India's diverse agricultural landscape.
- **Improved Barrier Properties:** Barrier properties are crucial for preserving the quality of perishable items such as dairy, meat, and fresh produce, which are critical to the Indian food industry. Scientists are working on biopolymers that can provide better moisture, oxygen, and light barriers, improving the shelf life of packaged goods. Biodegradable films with improved barrier functions will enable the packaging of products like fruits and vegetables in humid or tropical climates, which are a challenge in many parts of India.
- **Agricultural Waste Utilization:** With India being a major producer of agricultural waste, the development of biopolymers derived from these byproducts—such as rice husk, wheat straw, and corn stalks—offers a sustainable solution. The use of these materials in biopolymers could create a closed-loop system, turning waste into valuable packaging materials and helping reduce the environmental impact of traditional plastic

production.

Smart Biodegradable Packaging

As India's agricultural sector continues to grow, the need for more efficient supply chain management and waste reduction becomes more pressing. Smart biodegradable packaging is poised to play a significant role in addressing these challenges:

- **Sensors for Freshness Monitoring:** Integrating sensors and freshness indicators into biodegradable packaging can help monitor the condition of perishable goods during transit and storage. These sensors could detect factors such as temperature, humidity, and gas composition, providing real-time data on the freshness of agricultural products like vegetables, fruits, and dairy. For instance, for products like mangoes, a sensor could monitor the ripening process, alerting distributors and retailers when they need to be sold or consumed.
- **Reduction of Food Waste:** In India, food wastage is a significant issue, with a large portion of produce spoiling due to inadequate storage and transport conditions. Smart packaging can help reduce food waste by providing more precise information about the quality of the food. By alerting supply chain stakeholders to changes in temperature or humidity, smart biodegradable packaging can ensure that products are consumed or sold in time, reducing waste, especially in rural and semi-urban areas where distribution systems can be underdeveloped.
- **Integration with IoT (Internet of Things):** In the Indian context, the adoption of IoT-enabled smart packaging could significantly improve the agricultural supply chain. Farmers, wholesalers, and retailers could track real-time data about product freshness and quality through mobile applications, allowing for more efficient inventory management and reducing losses in the farm-to-table journey.

Nanotechnology

Nanotechnology is increasingly being explored as a means to enhance the properties of biodegradable packaging in India. By incorporating nanomaterials, biodegradable packaging can be made more durable, versatile, and effective in protecting agricultural products:

- **Improved Mechanical Properties:** Nanomaterials, such as nanocellulose or clay nanoparticles, can be used to reinforce biodegradable polymers. This could help create

packaging that is not only strong but also lightweight, an essential feature for packaging bulk agricultural products in India. For example, biodegradable bags and containers for storing grains, pulses, and vegetables would benefit from enhanced durability, which is crucial for India's vast agricultural logistics sector.

- **Barrier and Resistance Enhancement:** Nanotechnology can be used to improve the barrier properties of biodegradable packaging, making it resistant to moisture, oxygen, and UV light. This is especially important for packaging perishable agricultural commodities like dairy and fresh meat, where maintaining product integrity is critical. Nanotechnology could help make biodegradable packaging more effective at preserving food and extending shelf life, particularly in India's hot and humid climate.
- **Food Safety and Preservation:** Nanotechnology could also improve food safety by providing antimicrobial properties to biodegradable packaging. Research into using silver or zinc oxide nanoparticles, for example, can help reduce bacterial growth on food packaging, ensuring the preservation of agricultural products during transport. This innovation would be particularly beneficial for India's large-scale export of perishable goods like fresh fruits and vegetables.

Conclusion

Biodegradable packaging represents a transformative step towards sustainability in the agricultural sector. It not only mitigates environmental pollution caused by conventional plastic packaging but also promotes a circular economy by utilizing agricultural residues. With increasing consumer awareness, government policies, and advancements in biodegradable materials, the adoption of eco-friendly packaging is becoming a necessity rather than an option. As India continues to face challenges related to plastic waste, the shift towards biodegradable packaging offers a sustainable solution that aligns with national and global environmental goals. By integrating biodegradable packaging into agricultural supply chains, stakeholders can enhance product quality, reduce waste, and contribute to a healthier ecosystem. The future of agricultural packaging lies in sustainable innovations, and embracing biodegradable alternatives is a critical step towards ensuring a greener planet for future generations.

Volume: 05 Issue No: 12

THE NIGHT BEETLE BURN: HOW A TINY INSECT CAUSES BIG SKIN TROUBLES

Article ID: AG-VO5-I12-95**Vignesuwar T***

Undergraduate Student, School of Agricultural sciences, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India

*Corresponding Author Email ID: ttvignesuwar@gmail.com

Introduction

In a world full of such unpleasant encounters with insects, a mini scissortail beetle named *Paederus* spp., generally known as the Nairobi fly, is quite a contrarian to the rest, as it does not cause the human kind with either sting, or bite, or aggression—it makes them suffer without these three. Instead, it is a chemical attack: pederin, one of the most powerful vesicant irritants in nature, is only released when the insect is crushed against the skin of a human. The Nairobi-fly-caused-wound-to-the-skin, also called the *Paederus* dermatitis, has spread all over the African and Asian continents, and in Indian cities as well. Once a rare and astonishing event, this situation has been recorded as an emerging dermatological and public health problem now. The reports of incidents from places as different as South Sudan to Kerala, Lucknow to Ethiopia, and Sikkim to Tanzania all have the same plot: i.e.—urbanization, artificial lighting, climate changes, and human behaviour are, together, paving the way for the insects to come to the living rooms, lodges, farms, and skyscrapers of the cities.

The *Paederus* Beetle:

Though the “Nairobi fly” is the popular name given to the *Paederus* insects in East Africa, these creatures are more accurately described as rove beetles (family Staphylinidae). They are slim, long-bodied beetles with a skinny tail, small wings, and the typical black-orange or metal-like color. Slightly (7–10 mm), they attain medical importance only when they are crushed and hurl pederin, a very powerful vesicant that causes *Paederus* dermatitis, into the environment.

Paederus beetles prefer to live among the warm and muggy agricultural surroundings of paddy fields, sugarcane farms, wetlands, and places where there is a lot of rotting plant matter. As they are night creatures and phototropic, they will, without a doubt, be attracted to neon and fluorescent lighting, thereby having the chance of coming into contact with humans during the monsoon season.

There are more than 250 worldwide species of Paederus, and 43 species have been identified in India, among which *P. melampus* is the primary etiological agent for local epidemics. The likes of *P. brasiliensis*, *P. columbius*, and *P. peregrinus* are examples of such species that, in respective areas, i.e., South America, Africa, and Southeast Asia, induce similar dermatitis. Regardless of the differences between the regions, all of them have the unique feature of generating pederin that makes them important irritant contact dermatitis worldwide agents.



Paederus dermatitis is a type of skin chemical burn. The throwing away the beetle from the skin is the most common mistake that leads to the crushing of the beetle and thus the traumatization of the skin with this insect. Pederin, which paederus beetle releases, is a cytotoxic agent that inhibits DNA and protein synthesis.

Paederus dermatitis is almost always accompanied by the burning sensation that precedes the redness of the affected skin. After a few hours, the characteristically linear “whiplash” marks

become visible, and the area where the blisters or pustules will form is developing in the next 24 to 48 hours. Often, the unintentional spreading of the poison may result in “kissing lesions” on the sides where the skin folds touch. The skin discoloration accompanying this disease can last for several weeks although the acute reaction may disappear after a few days. This disease is frequently confused with fungal infections, herpes zoster, allergic dermatitis, or burns due to similar symptoms and therefore, the condition is often misdiagnosed, which results in delayed treatment.

Other than the skin lesions, the *Paederus* toxin is capable of inducing *Paederus* keratoconjunctivitis if the contaminated fingers come in contact with the eyes. “Nairobi red eye” characterized by this symptomatology includes swollen eyelids, overproduction of tears, conjunctival redness, and a feeling of “grittiness” due to the presence of a foreign body in the eye.

A Trail of Outbreaks: From Hostels to High-Rises

Paederus dermatitis has gradually spread its wings over the last twenty years and can now be found everywhere from college hostels, semiurban homes to high-rise apartments across both Africa and Asia. The main reasons for the insect's expanding territory far and wide have been the increase in artificial lighting, rapid urbanization, and changing environmental patterns.

1) When Dermatitis Requires Surgery: A Rare but Remarkable Case - Nasal Ala Reconstruction, Kenya (2025): Although most of the time the situation is less severe, in deep rare tissue destruction has been caused by Nairobi fly injuries. After she got delayed treatment of a toxin-induced ulcer, a woman in Kenya developed a full-thickness nasal alar defect. Reconstructive surgeons brought back the nasal framework with a conchal cartilage graft and a pedicled nasolabial flap for skin covering. The case is used as an example that, on occasion, *Paederus* dermatitis may lead to severe tissue loss which in turn may call for advanced surgical intervention although it is generally self-limiting.

2) Urban High-Rise Outbreak: Lucknow, India (2025): The multi-storied residential complex in Lucknow was the scene of a drastic example where around 5–10% of the residents developed painful, burn-like lesions. *Paederus* beetles were attracted by the bright evening lights to the window panes and indoor surfaces. They were even several floors above the ground. The presence of typical *Paederus* species was confirmed by the entomological sample taken. The

report shows how the modern lighting and vertical urban growth are the factors that are bringing these insects to the places that people considered low-risk before.

3) Monsoon-Linked Campus Epidemic: Sikkim (2022): The large outbreak at the residential college campus brought to light the behavioural and environmental vulnerabilities that had been there unnoticed. Influencing factors to the increase of the cases were late-night lighting, not removing insects from the bed linen, using uncovered clothing, and crushing the beetles instead of brushing them away.

4) Community Outbreak: Boditi Town, Ethiopia (2018): In the case of Boditi Town, Ethiopia, there was an incident of 45 cases which led to the investigation of the role of household surroundings in disease risk. The surroundings of the homes which had fruit trees, waste piles, and poorly screened windows—together with the lighting at night—were the main causes of the infestation. Children aged 8–15 years were the most affected, and lesions on the face and neck were especially common among them.

Why Are Outbreaks Increasing - Understanding the Ecological and Social Drivers

1) Artificial Lighting: *Paederus* beetles are strongly positively phototactic, thus they are strongly attracted to white fluorescent lamps, UV lights, and brightly lit indoor areas. The urban lighting that is spreading—mostly in high-rise buildings—is the factor that is taking beetles to human areas. As a result of there being more human-beetle interactions, the number of cases is going up.

2) Urbanization and Changing Vegetation: When cities are being built and nature is losing its vegetative cover, the beetles are forced to find new microhabitats. People planting vegetables in their balconies, using ornamental plants, and the damp corners around residential complexes are perfect hiding places for the little creatures and hence they are coming closer to human activity.

3) Climate and Rainfall Patterns: The *Paederus* are best to reproduce in a humid monsoon like conditions. One of the factors consisted of the El Niño effect, which is causing prolonged moisture and vegetative growth, which in turn is leading to a large increase in the number of outbreaks in different countries at the same time.

4) Human Behaviour: Most of the time people's everyday habits that they unknowingly do increase their exposure. For example, sleeping with the lights on, sitting near an illuminated balcony, crushing a beetle on one's skin, and not using protective window screens. All these activities put people in more frequent contact with the toxin.

Prevention: Lessons Shared Across Studies

- Understand how a Paederus beetle looks like and do not crush it on your skin.
- Close your doors and windows or put on the proper screens.
- Wear a bed net when you sleep, preferably one that is permethrin-treated.
- Putting a mesh or net under lights will help in catching the beetles that fall off.
- Don't ever rub your eyes or touch the lesions after the contact.
- Doing it gently, blow or brush the beetles off your skin and wash the area.
- Remove the excess vegetation around your house so that there will be fewer places for the beetles to rest.





Volume: 05 Issue No: 12

GROWING EXPERIENCES: THE ROLE OF AGRICULTURAL EXTENSION SERVICES IN PROMOTING AGRO-TOURISM

Article ID: AG-VO5-I12-96

Dr. S.R.Padma*

Assistant professor (Agricultural Extension), Tamil Nadu Agricultural University, Coimbatore-3.
Tamil Nadu, India

*Corresponding Author Email ID: padmasr@tnau.ac.in

Introduction

Agriculture and tourism are traditionally seen as separate sectors. However, with the growing demand for authentic rural experiences, agro-tourism (also known as agritourism) has emerged as a promising approach that blends agricultural practices with tourism activities. Agro-tourism invites visitors to participate in farm life, learn about rural culture, and experience agricultural production firsthand, thereby creating new income streams and strengthening rural economies.

Agricultural extension services—designed to connect farmers with research, knowledge, and markets—are uniquely positioned to support and boost agro-tourism development. This article explores how extension services can promote agro-tourism, the benefits of doing so, and the challenges that remain.

Understanding Agricultural Extension Services

Agricultural extension services are systems and programs that help farmers, rural communities, and other stakeholders access knowledge, technologies, and practical skills for improved agricultural productivity and livelihood outcomes. Traditionally, these services disseminate information, provide training, and link farmers with research institutions and markets.

Beyond technology transfer, modern extension services also support community development, marketing, and diversification of rural enterprises—creating fertile ground for agro-tourism to flourish.

What is Agro-Tourism?

Agro-tourism is a form of tourism that brings visitors to farms or ranches where they can participate in recreational, educational, cultural, or entertainment activities related to agriculture. Common offerings include farm tours, u-pick activities, farm stays, and hands-on agricultural experiences. Besides providing farmers with alternative income, agro-tourism educates visitors about farm life and sustains rural heritage and landscapes.

How Extension Services Promote Agro-Tourism

1. Education and Capacity Building

Extension officers can provide training to farmers on how to design and manage agro-tourism products and services. This includes guidance on hospitality, safety protocols, visitor engagement, and experience design. According to research, effective extension support can facilitate demonstrations, participatory training, and workshops that build both agricultural and tourism skills.

2. Knowledge Transfer and Communication

Extension services play a vital role in bridging the gap between research and practice. By sharing information about rural tourism trends, sustainable practices, and customer expectations, extension agents help farmers make informed decisions about entering agro-tourism.

3. Networking and Partnerships

By connecting farmers with tourism associations, local governments, and cultural organizations, extension services help build support networks that can promote agro-tourism at regional or national levels. Partnerships can also facilitate marketing, quality standards, and funding opportunities for agro-tourism ventures.

Benefits of Linking Extension with Agro-Tourism

Economic Diversification and Income Growth

Agro-tourism provides alternative revenue streams to farmers, reducing dependence on crop yields alone. This diversification can enhance economic resilience in rural communities, making farms more sustainable in the face of market or climate fluctuations.

Community Development and Cultural Preservation

Agro-tourism can help preserve rural traditions and local culture by exposing visitors to traditional farming practices, cuisine, and crafts. This exposure enriches cultural understanding and instils pride among community members.

Public Awareness and Education

Visitors gain a deeper appreciation of agriculture when they engage in experiential learning activities like harvesting, cooking farm produce, or attending farm workshops. This educational aspect aligns with extension goals of raising awareness and knowledge about agriculture.

Challenges and Considerations

While extension services have the potential to significantly promote agro-tourism, challenges remain:

- Limited training for extension agents on tourism-specific skills. Extension professionals need competencies not only in agriculture but also in marketing and visitor services.
- Infrastructure and resource constraints that can hinder the development of agro-tourism facilities.
- Coordination gaps between agricultural policies and tourism strategies, requiring stronger multi-sectoral collaboration.

Conclusion

Agricultural extension services are a powerful catalyst for agro-tourism development. By providing education, facilitating knowledge transfer, and fostering partnerships, extension agents can help rural farmers diversify incomes, preserve cultural heritage, and enhance community well-being. With dedicated training and integrated strategies, agro-tourism can become a sustainable avenue for rural prosperity.

References

- Extension and Outreach. (n.d.). *Linking research and practice: The role of extension on agritourism development in the United States*. Penn State Extension and Outreach.
- Phumrungruang, B., & Bacongus, R. (2020). *Agro-tourism as an extension strategy to promote agriculture in the Northern Region of Thailand*. *Journal of Public Affairs and Development*.
- Sharanya Yadav, P. (2025). *Agri-tourism: A sustainable path to rural prosperity and cultural preservation*. *NG Agriculture Insights*, 1(1), 10–12
- Tripathi, V. K., & Tiwari, M. V. (2024). *Agro tourism: Approaches of tourism by introducing agriculture tourism*. *International Journal of Agriculture Extension and Social Development*.

ROLE OF LIGNIN IN PLANT DEFENCE SYSTEM AND MAKING FIT FOR MECHANICAL HARVEST

Article ID: AG-VO5-I12-97**Kavithamani, D^{1*}, N. Premalatha² and M. Umadevi³**¹Assistant Professor (PBG), Department of Millets, TNAU, Coimbatore²Associate Professor (PBG), Department of Cotton, TNAU, Coimbatore³Assistant Professor (PBG), Department of Rice, TNAU, Coimbatore, Tamil Nadu, India

*Corresponding Author Email ID: kavithamani@tnau.ac.in

Introduction

Lignin is a complex, organic polymer that acts as a natural glue, binding plant cells and fibres together, providing structural support, rigidity, and resistance to decay, making wood strong and allowing plants to grow tall. It is the second most abundant organic polymer on earth after cellulose (Anushikha and Gaikwad, 2023), filling spaces between cellulose and hemicellulose in plant cell walls, especially in wood and bark, and playing a crucial role in water and nutrient transport.

It is a carbohydrate and an irregular, phenolic compound that provides structure and support for plant. Lignin in plants is found in and between the cell walls of plants, serving to bind cells and lend durability to plant matter. It is a vital, major biological component of all manner of plants, from woody trees to plants with freestanding stems to crunchy vegetables. Lignin is the second most common biological material on the planet, where the first being cellulose, which makes up the cell walls that lignin supports. Lignin is a huge source of sequestered carbon, accounting for 30% of all biological carbon, and up to 20% of the dry weight of all woody plants. This also makes it one of the most abundant sources of renewable carbon on earth.

Function of lignin in plants defence

Lignin is a durable, waterproof polymer and in plants that serves as a kind of "skeleton" or "backbone," providing structure and support. Lignin is a branching material that holds a plant

together and keeps the structure of the plant stable. It is most prevalent in woody trees and is responsible for most of their strength. Lignin also keeps out diseases, toxins and bugs while keeping water inside. Lignin is a carbohydrate. Therefore, though it looks rather complex, its molecular structure consists of atoms only of carbon, hydrogen and oxygen.

Lignin is derived from three main types of monolignols viz., p-Coumaryl alcohol (p-hydroxyphenyl or H unit), coniferyl alcohol (guaiacyl or G unit) and sinapyl alcohol (syringyl or S unit). The H unit in the lignin structure is characterized by a single hydroxyl group attached to the aromatic ring. Coniferyl alcohol governs the formation of guaiacyl (G) units, which hold a methoxy group ($-OCH_3$) and a hydroxyl group on the aromatic ring. Sinapyl alcohol forms syringyl (S) units, distinguished by two methoxy groups attached to the aromatic ring (Ninkuu *et al.*, 2023). The oxidative coupling reaction between three monolignols polymerization creates a complex and robust three-dimensional network of cross-linked units. The comparative profusion and occurrence of H, G, and S units can differ among different plant groups and tissues, influencing the physical properties and functions of this natural polymer (Al-Khayri *et al.*, 2023; Eynck *et al.*, 2012; Hano *et al.*, 2006). The cross-linked lignin structure provides firmness, strength, and resistance to disintegration, making it a valuable component of the plant cell wall that contributes to its antimicrobial capabilities against pathogens.

Lignin deposition in the infection zone is a significant defence strategy in resistant plants against biotrophic (Rust, smut, downy mildew disease-causing pathogens), hemi-biotrophic (*Colletotrichum* sp.), and necrotrophic pathogens (*Sclerotinia*, *Erwinia*, *Macrophomina* and *Fusarium*). This defence mechanisms also protects against Aphids and whiteflies as sucking pests and virus vectors by strengthening infection sites and limiting virus colonization and spread (Ma, 2012; Ninkuu *et al.*, 2023).

Additionally, lignin-mediated defences minimize the activity of enzymes and toxins released by bacteria and fungi while restricting water and nutrient availability to the invaders, enhancing plant resistance. Disruption of lignin biosynthesis in biotrophs promotes pathogen sporulation, highlighting lignin's importance in plant defense mechanisms (Gao *et al.*, 2021). Some of the sustainable managing strategies employed during integrated disease management of plant pathogens have revealed the function of lignin-mediated defence. The colonization of endophytes in the rhizosphere and phyllosphere was correlated with lignin-driven disease resistance in plants. Likewise, the use of indoleamine, such as melatonin, has been documented

to enhance plant redox network and reactive species signalling that also involve lignin deposition and induced host plant resistance (Jiao *et al.*, 2016; Li *et al.*, 2016). With the advent of gene editing tools, the role of lignin biosynthetic genes has been established through techniques such as virus-induced gene silencing. Moreover, genomics, transcriptomics, and proteomics have deciphered the role of these biochemicals in plant resistance and susceptibility (Ma, 2012; Ninkuu *et al.*, 2023; Soni *et al.*, 2021).

Mechanical harvesting

Lignin is vital for mechanical harvesting because it provides the structural rigidity and stem strength that prevent crops from bending or breaking (a condition called lodging). This structural integrity ensures the plants remain upright, allowing mechanical harvesters to process them efficiently without significant crop loss.

Lignin's main functions in plants are providing structural support (like a plant's skeleton for height & strength), enabling efficient water transport (by waterproofing xylem), and offering protection against pathogens, toxins, and pests, crucial for terrestrial life and plant survival. It reinforces cell walls, preventing collapse, and its hydrophobic nature ensures water moves upward from roots to leaves.

Functions of lignin in mechanical harvesting

Mechanical Strength and Rigidity:

Lignin acts as a natural "glue," binding cellulose and hemicellulose fibres within plant cell walls to form a rigid, three-dimensional network. This reinforcement is particularly concentrated in the secondary cell walls of stems and roots, providing the stiffness and compressive strength needed to withstand environmental forces like wind, gravity, and the physical stress of harvesting machinery.

Lodging Resistance:

Lodging, the permanent displacement of the stem from the vertical position, is a critical problem in agriculture that significantly impacts crop yield and makes mechanical harvesting difficult. Plants with higher lignin content in their stems and culms exhibit increased lodging resistance, a key pre-condition for successful, high-efficiency mechanical harvesting.

Vascular Integrity and Water Transport:

Lignin waterproofs the xylem vessels, enabling efficient water and nutrient transport throughout the plant. This stability prevents the vascular system from collapsing under the

negative pressure generated during water transport, which is crucial for the overall health and upright growth required for harvesting.

Defence Mechanism:

Lignin provides a physical and chemical barrier that protects plants from pests, fungi, and pathogens. This inherent resistance ensures a healthier, intact crop at harvest time, further contributing to a successful yield.

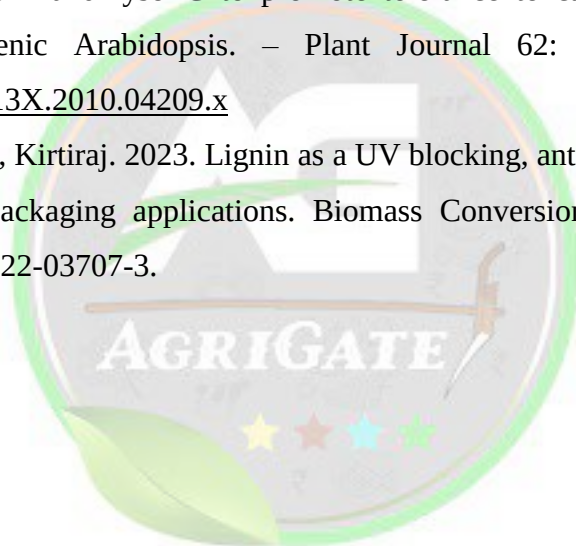
Conclusion

Lignin is the second most abundant plant-based material on Earth after cellulose. It is an organic polymer found in large quantities as an important structural component in plants. Lignin acts as a binder for the polysaccharides (cellulose, hemicellulose, and pectin) that make up most of plant cell walls thus maintaining the integrity of the plant cell. It is known as a material with excellent antioxidant and UV protection effects due to its rich polyphenol content. Lignin, a complex and abundant biopolymer derived from plant cell walls, has recently received considerable attention as a potential candidate for innovative applications in a variety of fields. Lignin is an abundant macromolecule obtained from renewable biomass, especially as a byproduct of the cellulose extraction process. Due to its complex polyphenol structure, it has various functional properties such as antioxidant, antibacterial, antifungal, and UV protection, making it an excellent multifunctional material for use in plant defence and mechanization in farming activities.

References

- Ninkuu, V., Yan, J., Fu, Z., Yang, T., Ziemah, J., Ullrich, M. S, 2023. Lignin and its pathway-associated phytoalexins modulate plant defense against fungi. *J. Fungi* 9 (1), 52. [https://doi: 10.3390/jof9010052](https://doi.org/10.3390/jof9010052).
- Al-Khayri, J.M.; Rashmi, R.; Surya Ulhas, R.; Sudheer, W.N.; Banadka, A.; Nagella, P.; Aldaej, M.I.; Rezk, A.A.-S.; Shehata, W.F.; Almaghasla, M.I. 2023. The Role of Nanoparticles in Response of Plants to Abiotic Stress at Physiological, Biochemical, and Molecular Levels. *Plants* 2023, 12, 292. [doi.org/ 10.3390/plants12020292](https://doi.org/10.3390/plants12020292).
- Hano, C., Addi, M., Bensaddek, L., Cronier, D., Baltora-Rosset, S., Doussot, J., Maury, S., Mesnard, F., Chabbert, B., Hawkins, S. 2006. Differential accumulation of monolignol-derived compounds in elicited flax (*Linum usitatissimum*) cell suspension cultures. *Planta* 223: 975-989. <https://doi.org/10.1007/s00425-005-0156-1>.

- Ma, B., Gao, L., Zhang, H. 2012. Aluminum-induced oxidative stress and changes in antioxidant defenses in the roots of rice varieties differing in Al tolerance. *Plant Cell Rep* **31**, 687–696. <https://doi.org/10.1007/s00299-011-1187-7>
- Eynck, C., Seguin-swartz, G., Clarke, W. E., Parkin, I. A. 2012. Monolignol biosynthesis is associated with resistance to *Sclerotinia sclerotiorum* in *Camelina sativa*. – *Molecular Plant Pathology* 13: 887-899. <https://doi.org/10.1111/j.1364-3703.2012.00798.x>.
- Li, H., Yang, Y., Wang, Z., Guo, X., Liu, F., Jiang, J., Liu, G. 2016. BpMADS12 gene role in lignin biosynthesis of *Betula platyphylla* Suk by transcriptome analysis. – *Journal of Forestry Research* 27: 1111-1120. <https://doi.org/10.1007/s11676-016-0229-y>.
- Gao, W., Li, H.-Y., Xiao, S., Chye, M. L. 2010. Acyl-CoA-binding protein 2 binds lysophospholipase 2 and lysoPC to promote tolerance to cadmium-induced oxidative stress in transgenic *Arabidopsis*. – *Plant Journal* 62: 989-1003 <https://doi.org/10.1111/j.1365-313X.2010.04209.x>
- Anushikha, and Gaikwad, Kirtiraj. 2023. Lignin as a UV blocking, antioxidant, and antimicrobial agent for food packaging applications. *Biomass Conversion and Biorefinery*. 14. 3. 10.1007/s13399-022-03707-3.



THE POWER OF ECOLABELLING: MAKING INFORMED CHOICES FOR A GREENER TOMORROW

Article ID: AG-VO5-I12-98**Dr. Rajeshwari Desai * and Miss Vijayalakshmi E****

* Senior Scientist, AICRP-WIA, University of Agricultural Sciences, Dharwad-5, Karnataka,

** MSc Scholar, University of Agricultural Sciences, Dharwad-5, Karnataka, India

*Corresponding Author Email ID: rajeshwarimd@uasd.in

Introduction

As consumers, we hold a remarkable yet often underestimated power—the power to shape the future of the planet through the choices we make in the marketplace. Each product we buy is not merely a commodity exchanged for money; it is, in essence, a *vote* cast for the kind of world we want to live in. When we choose a sustainably produced item, we support ethical manufacturing, responsible resource use, environmentally conscious companies, and ultimately a healthier planet. Conversely, purchasing unsustainable products indirectly fuels pollution, overexploitation of natural resources, and the generation of waste that the Earth struggles to absorb. This idea forms the backbone of sustainable consumption, a concept gaining widespread relevance in an age confronting climate change, biodiversity loss, water scarcity, and runaway consumerism.

In modern society, consumption patterns are heavily intertwined with economic growth and lifestyle aspirations. The convenience-driven culture has pushed global production to unprecedented levels, placing enormous pressure on natural systems. Every material good—from a simple paper cup to a smartphone—carries within it a hidden story: extraction of raw materials, energy use, transportation, packaging, labour, emissions, and waste disposal. These processes often remain invisible to the end user. A carton of milk, for example, may require land for cattle grazing, water for fodder cultivation, transportation fuel, processing energy, plastic or tetrapak packaging, and cold storage. Similarly, a mobile phone contains metals mined from distant regions, assembled in factories powered by industrial energy, and shipped across continents

before landing in a consumer's hands. When discarded, electronic waste releases toxins that harm soil, water, and human health.

While consumers are increasingly conscious of these environmental and social implications, the complexity of global supply chains makes it nearly impossible for an average person to quantify the real impact of a product. Most individuals neither have the time nor the expertise to investigate production methods, carbon footprints, or waste generation associated with every purchase. A critical gap exists between consumer intention and informed decision-making. People may want to choose sustainable alternatives but lack clear, credible information to guide them.

This is where ecolabelling emerges as a powerful solution. Ecolabels act as a bridge between producers and consumers, converting intricate environmental data into a simple, easy-to-recognize symbol displayed on products. In essence, an ecolabel is a reliable certification that guarantees a product meets specific environmental standards relating to energy efficiency, resource use, pollution control, recyclability, organic production, fair trade, or carbon emissions. By placing trust in ecolabels, consumers are empowered to make quick yet responsible purchasing choices, even without deep technical knowledge. These labels serve as high-integrity environmental communicators, condensing complex sustainability metrics into a single emblem that tells shoppers: "This product is better for the environment."

Beyond individual decision-making, ecolabelling plays an essential role in shaping market behaviour. When demand for eco-certified products increases, manufacturers and industries are encouraged or pressured to adopt greener processes. Thus, ecolabelling does not merely guide consumer choices; it drives systemic transformation. It creates a marketplace where environmental responsibility becomes an advantage rather than a burden. Over time, this can shift entire industries towards sustainable models, reduce emissions, conserve resources, and foster a circular economy.

The need for ecolabelling is more urgent today than ever before. The 21st century is marked by unprecedented environmental challenges. Rapid industrialisation, urbanisation, and mass consumption patterns have accelerated deforestation, greenhouse gas emissions, waste accumulation, and depletion of freshwater reserves. While policies and technological innovations are crucial, behavioural change among consumers is equally significant. Sustainable consumption reducing wastage, choosing eco-friendly goods, supporting ethical brands, and

preferring renewable materials holds substantial potential for lowering our ecological footprint. For such change to occur effectively, consumers must have transparent and trustworthy information, and ecolabels provide exactly that.

Ecolabelling

Ecolabelling is far more than just a badge; it is a critical, market-based tool that translates complex environmental performance data into a simple, trustworthy symbol, empowering consumers and driving corporate sustainability on a global scale.

Ecolabelling is a voluntary certification process that recognizes products or services that meet specific, independently verified environmental performance criteria throughout their life cycle. It serves as a seal of approval, typically awarded by a third-party, non-governmental, or public authority body.



The Foundational Framework-Ecolabelling Under the ISO Standard

The challenge of "Lack of Standardization" noted in present days is directly addressed by the International Organization for Standardization (ISO). To bring order and credibility to environmental claims, ISO developed a series of standards (ISO 14020 series) that categorize and regulate the communication of environmental performance. Understanding this framework is crucial, as it defines the trustworthiness and scope of different labels found in the market.

The Three Types of Environmental Labels ★ ★ ★ ★ ★

Ecolabelling schemes are broadly classified into three major types, each defined by a specific ISO standard:

1. Type I Environmental Labelling (ISO 14024): The Gold Standard

Type I labels represent the most rigorous and comprehensive form of environmental certification. They are defined as voluntary, multiple-criteria-based, third-party programmes that award a licence to products indicating their overall environmental preferability within a product category.

- **Criteria:** Based on a Life Cycle Assessment (LCA), criteria cover multiple environmental impacts (e.g., energy use, waste, water pollution) from raw material extraction to disposal.
- **Verification:** Certification is carried out by an independent third party (Competent Body), which ensures transparency and impartiality.

- Selectivity: These labels are selective, typically awarded only to the top 10–20% of environmentally preferable products in a given market.
- Examples: The EU Ecolabel, Nordic Swan, and Germany's Blue Angel.

2. Type II Environmental Claims (ISO 14021): Self-Declaration

These are environmental claims that are self-declared by manufacturers, importers, or distributors, without third-party certification.

- Verification: While they do not require independent verification, claims must be accurate, non-misleading, and verifiable by the company itself.
- Scope: They often focus on a single attribute (e.g., "Contains 50% Recycled Material," "Recyclable Packaging").
- Risk: They carry a higher risk of contributing to greenwashing if the claims are vague or unsubstantiated, though the ISO standard explicitly bans the use of vague terms like 'sustainable'.

3. Type III Environmental Declarations (ISO 14025): Data and Transparency

Type III declarations, often called Environmental Product Declarations (EPDs), are comprehensive, quantified information sheets that communicate the environmental impact of a product throughout its life cycle.

- Criteria: The information is based on a rigorous Life Cycle Assessment (LCA), following pre-established Product Category Rules (PCRs).
- Verification: The underlying data and LCA methodology are independently verified.
- Purpose: Unlike Type I, which indicates overall preferability, Type III declarations are informative and comparative, primarily aimed at business-to-business (B2B) transactions, such as public procurement or construction tenders, allowing purchasers to compare products based on objective environmental data.

The Certification Roadmap-How to Get Ecolabelling

Achieving a credible Type I ecolabel, such as the EU Ecolabel or a national equivalent, is a rigorous process designed to ensure that the product meets high environmental and performance standards. This detailed, multi-step roadmap ensures the label's trustworthiness and prevents greenwashing.

Step 1: Establish Product Category and Review Criteria

The company first determines if its product or service falls under an existing product group for the desired ecolabel (e.g., graphic paper, cleaning products, textiles).

- **Criteria Compliance:** The company must obtain and thoroughly review the specific environmental and performance criteria established for that product category. These criteria are revised periodically (often every four years) to reflect technical innovation and market changes.
- **Legal Prerequisite:** A fundamental precondition for even applying is demonstrating full compliance with all relevant national and international environmental legislation.

Step 2: Conduct Life Cycle Assessment (LCA) and Testing

Before application, the company **must gather** the scientific evidence and data necessary to substantiate its claims against the criteria.

- **LCA Data:** The criteria are set based on a scientific consideration of the product's entire life cycle, including raw material extraction, production, distribution, use, and end-of-life (e.g., recyclability).
- **Laboratory Testing:** For many criteria (e.g., chemical content, biodegradability, energy consumption), the company must submit samples of the product for testing by accredited laboratories to generate verifiable data.

Step 3: Application and Submission ★ ★ ★ ★

The applicant submits a formal application to the designated Competent Body (the third-party certifier) in the relevant region.

- **Documentation:** This submission includes the results of all tests, compliance reports, evidence of legal compliance, and a detailed description of the product, manufacturing processes, and supply chain. For labels like the EU Ecolabel, specific technical user manuals assist with this process.

Step 4: Third-Party Verification and Audit

This is the critical phase where the independent Competent Body assesses the application's integrity.

- **Verification:** The auditor reviews all submitted documentation, test reports, and compliance statements to confirm they meet the required criteria.

- **Site Inspection:** Depending on the program, the process may include site inspections and audits of the manufacturing facilities to verify the claimed production practices, supply chain integrity, and quality requirements.
- **Assessment:** The goal is to ensure that the product not only reduces its environmental impact but also maintains fitness for use and quality requirements.

Step 5: Awarding the Licence

If the Competent Body is satisfied that the product fully complies with all environmental and performance criteria, the license is awarded.

- **Licence Use:** The company is then authorized to display the ecolabel logo on the product and in promotional materials for a specified period, typically contingent on continued compliance.

Step 6: Compliance Monitoring and Renewal

Certification is not a one-time event; it requires ongoing vigilance.

- **Monitoring:** The Competent Body typically conducts periodic compliance monitoring to ensure the product or service continues to meet the criteria, especially in case of changes to the manufacturing process or materials.
- **Revision:** Since criteria are regularly updated (e.g., every four years) to reflect the best available environmental performance in the market, companies must apply for renewal and meet the new, often stricter, standards to maintain their certification.

Explaining Key Ecolabels in Action

To illustrate the diversity and rigor of environmental performance standards, here are explanations of three major ecolabels, representing different types of focus and scope.

1. The EU Ecolabel (Type I - Multi-Criteria)

The **EU Ecolabel** is the official voluntary, Type I environmental label for products and services across the European Union, recognized throughout Europe as well as Norway, Iceland, and Liechtenstein.



- **Criteria and Focus:** It is based on a **life cycle approach**, meaning it assesses the environmental impact from the extraction of raw materials to the distribution and end-of-life. The criteria are strict, ensuring labeled goods have a lower environmental footprint,

contain less hazardous chemicals, generate less waste and CO₂ during manufacturing, and are often designed to last longer and be easier to repair.

- **Significance:** It serves as a single, pan-European mark of green excellence, helping consumers trust their purchase decisions and rewarding manufacturers who design durable and repairable products. Its criteria are frequently used to inspire Green Public Procurement (GPP) policies.
- **Product Groups:** It covers a vast range of products and services, including cleaning products, paper, clothing, textiles, cosmetics, and tourist accommodations, but explicitly excludes food, beverages, pharmaceuticals, and medical devices.

2. Forest Stewardship Council (FSC) (Sector-Specific, Third-Party Verified)



The Forest Stewardship Council (FSC) is a global non-profit organization that sets standards for responsible forest management. While often categorized as a sector-specific certification, its stringent, multi-criteria, and third-party verified nature aligns with the trustworthiness of a Type I scheme.

- **Criteria and Focus:** FSC focuses on two main areas: **Forest Management (FM)**, ensuring a forest is managed sustainably (environmentally appropriate, socially beneficial, and economically viable), and **Chain of Custody (CoC)**, which tracks wood from the certified forest to the final consumer product. Products must contain at least a minimum share of certified and/or recycled material.
- **Significance:** It provides consumers with assurance that the wood, paper, or other forest-based product they purchase originates from a sustainably managed source. Its requirements are robust enough that other labels, like the EU Ecolabel for paper products, have aligned their criteria to require FSC (or equivalent) certification for the material origin.
- **Labels:** The common labels are **FSC 100%** (all material from certified forests), **FSC Recycled** (all material is recycled), and **FSC Mix** (material from certified forests, recycled material, and controlled wood).



3. ENERGY STAR (Single-Attribute, Government-Backed)

ENERGY STAR is an international standard for energy-efficient consumer products, originated by the U.S. Environmental Protection Agency (EPA). It is a highly recognizable label focused on a single, crucial environmental attribute: energy consumption.

- **Criteria and Focus:** The label is awarded to products that meet strict energy efficiency guidelines set by the government. The criteria focus on reducing greenhouse gas emissions and other pollutants caused by inefficient energy use. It certifies products in the **use phase** of their life cycle, where energy consumption is the highest.
- **Significance:** It helps consumers and businesses save money on energy bills and contributes significantly to climate change mitigation by driving demand for highly efficient electronics, appliances, and lighting.
- **Product Groups:** It covers over 75 different product categories, including office equipment, residential lighting, heating and cooling equipment, and major appliances. The use of the label is third-party certified and products must be tested by EPA-recognized laboratories.

Benefits of Ecolabelling

1. **Environmental Benefits:** Ecolabelling plays a crucial role in minimizing environmental degradation by encouraging industries to adopt sustainable production techniques. By promoting resource-efficient processes, it helps reduce greenhouse gas emissions, energy consumption, and air and water pollution. Products certified under ecolabel schemes often use renewable materials, biodegradable packaging, or have longer lifecycles, thereby lowering their environmental footprint. For example, eco-certified paper ensures responsible forest management and reduced deforestation, while energy-efficient appliances lower household emissions. Over time, ecolabelling contributes to climate change mitigation, biodiversity conservation, and sustainable natural resource use, fostering an ecologically balanced environment.
2. **Informed Consumer Choices:** One of the greatest strengths of ecolabelling is its ability to guide consumers toward environmentally friendly products. Many individuals want to consume responsibly but lack reliable information about product sustainability. Ecolabels simplify complex environmental data into a recognizable symbol, enabling consumers to identify greener alternatives quickly. This transparency builds trust between producers

and buyers, motivating consumers to support companies that prioritize environmental integrity. As awareness grows, ecolabels nurture environmentally responsible purchasing habits, transforming consumption into a conscious act of stewardship. Ultimately, consumer empowerment becomes a driving force that shapes sustainable market trends.

3. **Market Incentives for Sustainability:** Ecolabelling establishes a competitive market environment where sustainability becomes a valuable asset rather than an additional burden. Companies that earn eco-certification differentiate themselves and gain market advantages, such as increased sales, improved reputation, and access to green procurement schemes. This compels industries to invest in cleaner technologies, reduce waste, improve energy efficiency, and adopt ethical sourcing practices. As more firms pursue ecolabel certifications, the market naturally shifts toward higher environmental standards, making sustainability a norm rather than an exception. In this way, ecolabelling uses consumer demand as leverage to stimulate global greening of industries.
4. **Reduces Greenwashing and Enhances Credibility:** With increasing environmental awareness, many companies falsely claim their products are "eco-friendly" to attract customers—a practice known as greenwashing. Ecolabelling combats this by ensuring authenticity through strict certification criteria, third-party verification, and periodic audits. Products with legitimate ecolabels position themselves as trustworthy and accountable, protecting consumers from misleading claims. This transparency builds confidence in the sustainability market and maintains the integrity of environmental messaging.
5. **Supports Policy Goals and Sustainable Development Targets:** Ecolabelling aligns closely with global sustainability frameworks such as the UN Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production). Governments often integrate ecolabel criteria into public procurement systems, encouraging institutions to purchase certified goods. This reduces environmental impact on a national scale and promotes circular economy principles. Furthermore, ecolabelling supports carbon reduction targets, promotes waste minimization, and strengthens regulatory mechanisms, making it a valuable tool for environmental governance and policy implementation.

Challenges and Limitations

Greenwashing: A significant concern associated with ecolabelling is the risk of greenwashing, wherein companies intentionally mislead consumers by falsely portraying their products as environmentally friendly. Some firms may use self-declared, non-certified labels or vague terms such as “eco-safe,” “natural,” or “green” without meeting actual sustainability criteria. Others may exaggerate minor improvements to appear

responsible while continuing harmful practices in the background. This misrepresentation reduces consumer trust and dilutes the credibility of authentic ecolabels. In severe cases, it can lead to unfair market advantage for unethical companies, discouraging genuine efforts made by responsible businesses. Therefore, stringent verification, transparent auditing, and strict legal frameworks are necessary to prevent misuse of environmental claims and protect consumer interests.

Lack of Standardization Across Labels: Ecolabelling programs often differ in criteria, certification procedures, and environmental benchmarks based on regions, industries, or organizations. This lack of uniform global standards may confuse consumers, who struggle to compare products with multiple labels conveying different messages. For example, one label may focus on carbon footprint, another on recyclability, and yet another on organic inputs, making it difficult to determine which product is truly environmentally superior. Variation in stringency also exists—some certifications are rigorous and science-based, while others are lenient and easily attainable. Such inconsistencies may reduce the effectiveness of ecolabelling systems and hinder consumer confidence. Establishing harmonized frameworks, mutual recognition agreements, and awareness programs can help create clarity and strengthen label reliability.

Higher Cost and Limited Accessibility: Eco-certified products often cost more due to sustainable raw materials, ethical labour practices, and compliance expenses, making them less affordable for price-sensitive consumers. Likewise, certification processes can be expensive for small manufacturers, limiting their participation in eco-labelling schemes. This results in a market where sustainable choices may be available only to privileged consumer groups, slowing



widespread adoption. Supportive incentives, subsidies, and awareness campaigns can help bridge this gap.

The Future of Ecolabelling

As consumers become increasingly environmentally conscious, ecolabelling will play a crucial role in shaping the market. By supporting ecolabelled products, we can drive demand for sustainable goods and services, promoting a greener future for generations to come.

Make a Difference

Next time you're shopping, look for ecolabelled products. By making informed choices, you're contributing to a more sustainable future. Together, we can create a world where environmental responsibility is the norm, not the exception.

By incorporating ecolabelling into our daily lives, we can make a significant impact on the environment. So, let's make a conscious effort to choose ecolabelled products and support companies that prioritize sustainability. The future of our planet depends on it



DIPTERAN PESTS OF MUSHROOMS AND THEIR MANAGEMENT

Article ID: AG-VO5-I12-99

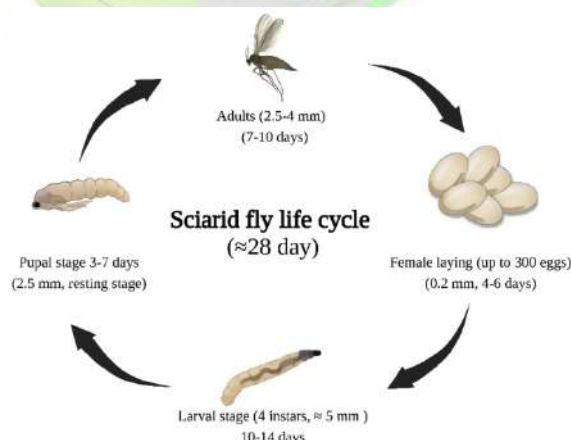
Dr. R.K. Gokulakrishnaa*

Assistant Professor in Agricultural Entomology, Department of Crop Protection,
MIT College of Agriculture and Technology (Affiliated to TNAU), Musiri-621211,
Tamil Nadu, India.

*Corresponding Author Email ID: entogokul230696@gmail.com

Introduction

Sciarid flies belong to the family *Sciaridae*, with the most economically damaging species primarily classified under the genera *Bradysia* and *Lycoriella*. Species of *Lycoriella* are predominantly associated with commercial mushroom cultivation, where they can cause substantial economic losses. Sciarid flies thrive in damp and humid environments and are commonly encountered in greenhouses worldwide. While they generally cause minimal damage to healthy, established plants, sciarids pose serious problems in cuttings, seedlings, and other young or actively growing plant material, where infestations can lead to significant crop losses.



Damage symptoms

Sciarid fly larvae primarily feed on organic debris and associated fungi; however, certain species are also capable of feeding on living plant tissues. Adult flies prefer humid environments

and are attracted to a wide range of pathogenic and non-pathogenic microorganisms, which serve as cues for oviposition.

Indirect damage arises when larvae and adults act as vectors of plant pathogenic fungi, including *Fusarium*, *Botrytis*, and *Verticillium*, facilitating the spread of diseases from infected to healthy plants. Direct damage results from larval feeding on plant roots. While larvae mainly consume decaying organic matter, algae, and fungi present in the growing medium, they may also attack root hairs, fine roots, and tender root, stem, and leaf tissues. In later instars, larvae may feed on plant stems. Feeding injuries further predispose plants to infection by soil-borne pathogens by providing entry points for pathogenic fungi. As larval movement is limited, plant mortality typically occurs in localized patches. Young plants grown under humid and well-watered conditions are particularly susceptible to sciarid fly damage.

Life cycle and appearance of sciarid flies

The life cycle of sciarid flies comprises the egg stage, four larval instars, a pupal stage, and the adult stage. Adult sciarid flies are small, grey to black insects measuring approximately 1–5 mm in length. They possess long, segmented antennae, relatively long legs, and transparent wings with distinct venation. The head is small and bears sucking mouthparts; however, adults feed little, if at all, during their short lifespan. Males are generally smaller than females. Adults are weak fliers and preferentially inhabit dark, damp environments rich in organic matter. Under favourable conditions, sciarid flies may occur throughout the year.

Eggs are minute (approximately 0.1–0.25 mm in length), yellowish-white in colour, and are laid on the soil or growing-medium surface near plant roots. Larvae are legless, translucent to whitish, and attain lengths of 5–12 mm with a diameter of 0.5–1.5 mm. A characteristic feature of the larva is its conspicuous black head capsule, which bears well-developed biting–chewing mouthparts. Pupation occurs within a small chamber in the soil or growing medium. The pupae are initially white, gradually turning yellow to brown as development progresses, and the posterior end of the pupa remains mobile.

Managing dark-winged fungus gnats in oyster mushroom cultivation using botanicals (Badshah *et al.* 2021)

Oyster mushroom cultivation is often affected by insect pests, particularly dark-winged fungus gnats (*Lycoriella ingenua*), which can significantly reduce yield and quality. To identify

eco-friendly management options, an experiment was conducted to evaluate the effectiveness of commonly available plant-based extracts against this pest.

Five treatments were tested: neem aqueous extract (5%), onion bulb extract (4%), garlic bulb extract (4%), eucalyptus leaf extract (6%), along with an untreated control. Among the treatments, neem aqueous extract proved to be the most effective in suppressing fungus gnat populations, recording the lowest number of adult flies. Garlic bulb extract was the next best treatment, while the highest pest population was observed in the untreated control.

The positive effect of neem treatment was also reflected in mushroom production. Neem-treated growing bags produced a significantly higher number of mushrooms and recorded the highest yield compared to all other treatments. In contrast, untreated bags showed poor mushroom production and the lowest yield. Neem treatment also resulted in higher biological efficiency and moisture content of mushrooms, indicating better crop health and quality. Overall, neem aqueous extract effectively reduced fungus gnat infestation and significantly improved oyster mushroom yield and quality. As it is safe, economical, and environmentally friendly, neem aqueous extract can be recommended as an important component of an Integrated Pest Management (IPM) strategy for managing *Lycoriella ingenua* in oyster mushroom cultivation.

Use of an Azadirachtin-Based Bioinsecticide for Managing Mushroom Flies (Drobnjakovic *et al.* 2019)

Mushroom flies (Sciaridae: Diptera), particularly *Lycoriella ingenua* (Dufour), are serious pests in commercial mushroom cultivation, causing yield losses and quality deterioration. This case study evaluates the effectiveness of an azadirachtin-based bioinsecticide (Ozoneem Trishul 1%) in comparison with a commonly used malathion-based chemical insecticide (Etiol tečni) under commercial production conditions.

The study was conducted at the commercial mushroom farm *Delta Danube* d.o.o., Kovin, using three growing chambers (B6, B7, and B8). The experiment followed a randomized block design with eight replications. Chamber B8 received the azadirachtin-based bioinsecticide at a dose of 0.5 ml/m², applied four times—once during casing and subsequently at seven-day intervals. Chambers B6 and B7 were treated with the malathion-based insecticide at a dose of 0.3 ml/m², applied twice on the third and sixth day after casing. Chamber B6 served as the untreated control.

Mushroom fly populations were monitored using yellow sticky traps placed in each chamber. The traps were collected weekly and replaced at seven-day intervals over four sampling periods. All collected traps were examined under a binocular microscope to identify and count mushroom flies. During the entire experimental period, only one mushroom fly species, *Lycoriella ingenua*, was recorded. At 15 and 22 days after treatment, the number of sciarid flies per mushroom block was significantly lower in the azadirachtin-treated chamber (B8) than in the malathion-treated chambers (B7 and B6). At 30 and 36 days after treatment, no significant differences were observed between the treatments and the control. However, when data were considered across the entire cropping period, the average number of sciarid flies per mushroom row remained significantly lower in the azadirachtin-treated chamber compared with both malathion-treated chambers.

This case study demonstrates that azadirachtin-based bioinsecticide can effectively suppress populations of *Lycoriella ingenua* in commercial mushroom production. Given its eco-friendly nature and comparable efficacy, azadirachtin represents a promising and safer alternative to conventional chemical insecticides for sustainable mushroom pest management.

Phorid flies *Megaselia halterata*

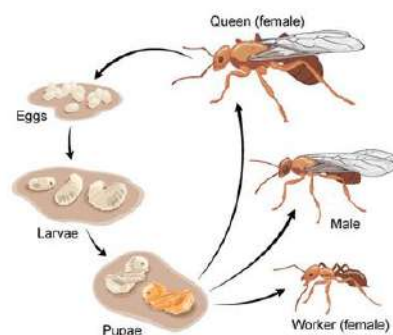
Especially *Megaselia halterata*, are increasingly being recognized as a **serious pest in commercial mushroom cultivation**, causing significant yield losses and quality issues worldwide. Where these pests were once considered minor, studies indicate that infestations can now reduce mushroom yields by **10–40%** in affected farms in India, the UK, the USA, and Europe due to direct feeding and transmission of disease organisms.

IPM is the sustainable strategy to manage phorid populations. It relies on combining preventive practices, monitoring, biological tools, and, when necessary, insecticides carefully chosen and timed to reduce pest pressure while protecting workers, consumers, and the environment.

Understanding Phorid Fly Biology and Damage

Adult phorid flies are small and agile, making them difficult to monitor and manage. They prefer to enter mushroom rooms after casing soil has been applied over the colonized compost, with larvae feeding on mushroom mycelia. Damage includes **tunnelling in beds, malformed fruit bodies**, and increased vulnerability to pathogens.

Control is difficult because many products effective against other mushroom fly pests (like sciarids) do **not** control phorids effectively. Traditional pesticides used against sciarids often have lower efficacy on *M. halterata*, compelling growers to adopt broader strategies.



Preventive and Cultural Practices

Prevention is the foundation of IPM:

- **Sanitation:** Routine cleaning and disinfection of rooms, tools, and growing surfaces reduce pest harbourage.
- **Compost and casing management:** Proper pasteurization and handling of these materials reduce initial pest infestations.
- **Environmental controls:** Maintaining optimal temperature, humidity and proper airflow reduce phorid development and adult activity.
- **Exclusion:** Installing insect-proof screens and minimizing gaps in ventilation systems prevent adults from accessing mushroom houses.

Such measures can substantially lower pest entry and slow population buildup.

Monitoring and Early Detection

Yellow sticky traps remain a simple, effective method to monitor adult phorid fly populations. Traps placed near entry points, vents, and above beds help growers track pest presence and timing of infestations, providing critical data to support timely intervention

decisions. Regular monitoring helps avoid unnecessary chemical use and is key to implementing IPM successfully.

Biological Control Options

Biological tools are increasingly important as part of integrated management:

- **Entomopathogenic nematodes (EPNs):** Nematodes from *Steinernema* and *Heterorhabditis* genera have been used to target larval stages in casing or compost. Some studies show **significant reduction in adult emergence** of mushroom flies using *Steinernema feltiae* and *S. carpocapsae*, while not harming mushroom yield.
- **Bacillus thuringiensis (Bt):** Bt var. israelensis (Bti) can reduce larval populations of dipterans. Although research is still evolving, it has shown control efficacy similar to some chemical insecticides in trials.
- **Predatory mites:** Certain Hypoaspis mite species and predatory mites like *Parasitus* spp. can feed on fly larvae, though results are variable and need further optimization.

These options are generally compatible with reduced-risk IPM strategies and can be integrated with monitoring and other practices.

Plant Extracts and Botanicals

Botanical extracts such as **azadirachtin** (from neem) and extracts of *Pimpinella anisum* and *Origanum onites* have demonstrated **repellent and larval inhibitory effects** against mushroom flies, with minimal impact on mushroom quality or yield.

Garlic extract has shown activity against adult flies at sufficient concentrations. While these options may not entirely replace controls, they can reduce pest pressure when combined with good sanitation and exclusion practices.

Chemical Control: Insecticides in the IPM Toolbox

Chemical insecticides are part of IPM only when pest pressure is high and other tools are insufficient. The review by Navarro et al. outlines several groups historically used against mushroom flies, though many faces **regulatory restrictions or resistance issues**:

- **Organophosphates:** Diazinon and chlorpyrifos were early tools incorporated into compost or casing soil with variable success. Diazinon at lower doses controlled phorids without harming mycelium, though higher doses risk yield loss.
- **Carbamates:** Bendiocarb applied to compost showed efficacy but has been linked to lower yields in some studies.

- **Insect Growth Regulators (IGRs):** Diflubenzuron and methoprene target insect development; however, their effectiveness against phorid flies has been mixed and sometimes limited.
- **Pyrethroids:** Variable results have been reported; pyrethroids are often used as **aerosol space sprays** rather than soil treatments to reduce adult populations.
- **Neonicotinoids and pyridine derivatives:** Newer compounds like thiamethoxam and pymetrozine have shown promise, albeit with regulatory and residue considerations.

Growers must weigh the benefits of chemical control against risks such as **residues in the harvest, environmental impact, and restrictions under sustainable pesticide directives.**

Conclusion: A Balanced IPM Strategy

Effective phorid fly management in **mushroom** cultivation cannot rely on a single control method. A **balanced, integrated approach** that emphasizes sanitation, monitoring, exclusion, biological control, plant-based repellents, and *judicious* insecticide use offers the best long-term solution.

By understanding phorid biology and integrating multiple control tools, growers can reduce pest impacts, protect mushroom yield and quality, and move toward more **sustainable production systems.**

Cecidomid Fly, *Mycophila speyeri*

Unlike sciarid or phorid flies, which are often noticed buzzing around the growing room, *M. speyeri* is rarely seen as an adult. The damage is almost entirely caused by the larvae, and it manifests in several distinct ways:

- **Mycelial Destruction:** The larvae feed voraciously on the mushroom mycelium. In the early stages (spawn run), they can eat the fungal threads so extensively that the compost appears "dead" or fails to produce mushrooms in certain patches.
- **"Browning" of Pins:** When larvae attack the developing pinheads, the pins often turn brown, become leathery, and fail to develop.⁴
- **Stem and Gill Infestation:** As the mushrooms grow, larvae crawl up the stems and congregate in the gills. They can tunnel into the mushroom tissue, leaving behind small, orange or white "tracks."

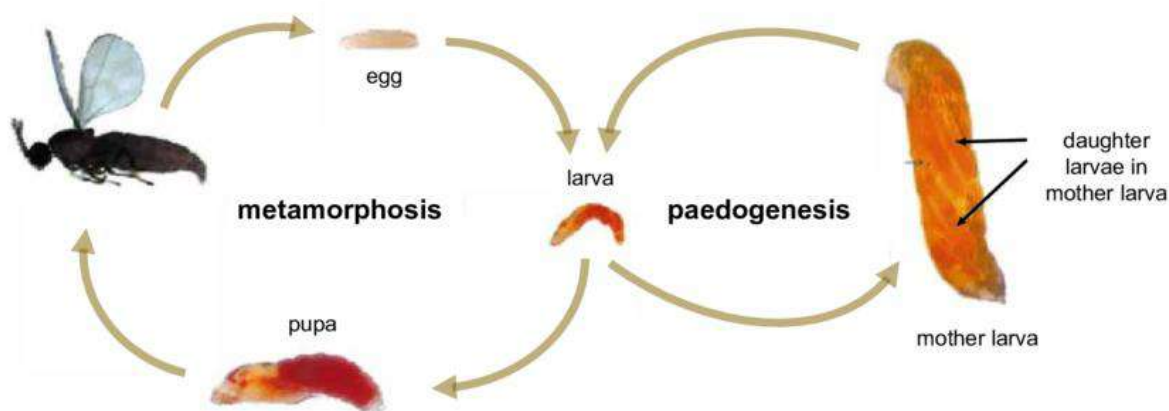
- **Marketability Loss:** Even if the mushroom grows to full size, the presence of tiny, wriggling larvae (often orange or creamy-white) on the cap or in the gills makes the crop unfit for sale.
- **Disease Vectoring:** Like other midges, they can inadvertently carry fungal spores (like Dry Bubble) or bacteria from one bed to another, compounding the crop loss.

The "Paedogenesis" Factor

What makes *M. speyeri* particularly dangerous is **paedogenesis** larval reproduction.

Skipping the Adult Phase: Under favourable conditions, a "mother larva" can give birth to 10–30 "daughter larvae" directly, without ever pupating or turning into a fly.

- **Explosive Growth:** Because they skip the long pupal and adult stages, their population can explode in just 4–6 day. A single larva introduced into a growing room can turn into millions within a few weeks.



Integrated Pest Management (IPM) Strategies

Because these midges are so small and reproduce so quickly, a "spray-after-you-see-them" approach rarely works. A successful IPM program relies on **Exclusion, Sanitation, and Biological Control.**

Prevention and Exclusion (The First Line of Defense)

- **Filter the Air:** Use high-efficiency filters on all air intakes to prevent adult flies from entering during the cooling and spawn-run phases.
- **Physical Barriers:** Ensure all doors are tightly sealed with weather-stripping and use fine mesh (16 mesh/cm) on ventilation openings.⁷

- **Strict Access Control:** Limit the movement of personnel between "old" (potentially infested) and "new" growing rooms.⁸

Sanitation and Cultural Control

- **Pasteurization:** Ensure Phase II compost is properly pasteurized (typically for several hours) to kill any larvae or eggs present in the substrate.
- **Cook-out:** At the end of the crop cycle, "cook out" the room with steam before removing the spent compost to prevent the pest from surviving for the next crop.
- **Waste Management:** Immediately remove and dispose of spent mushroom substrate far away from the production facility.

Biological and Chemical Control

- **Entomopathogenic Nematodes:** Beneficial nematodes, particularly *Steinernema feltiae* or *Heterorhabditis bacteriophora*, can be applied to the casing soil. These microscopic worms hunt down and kill midge larvae.
- **Botanicals:** Neem-based products or pyrethrins can be used as a "cold fog" to manage any adult flies that manage to enter, though they have limited effect on larvae deep in the compost.
- **Insect Growth Regulators (IGRs):** Chemicals like diflubenzuron can be applied to the casing to disrupt the moulting process of the larvae, preventing them from reproducing.

References

- Navarro, M. J., Escudero-Colomar, L. A., Carrasco, J., & Gea, F. J. (2021). *Mushroom phorid flies. A review. Agronomy*, 11(10), 1958. <https://doi.org/10.3390/agronomy11101958>
- Badshah, K., Ullah, F., Ahmad, B. *et al.* Management of *Lycoriella ingenua* (Diptera: Sciaridae) on oyster mushroom (*Pleurotus ostreatus*) through different botanicals. *Int J Trop Insect Sci* **41**, 1435–1440 (2021). <https://doi.org/10.1007/s42690-020-00341-2>.
- Drobnjaković, T., Marčić, D., Potočnik, I., Rekanović, E., Prijović, M., Milijašević-Marčić, S., & Stepanović, M. (2019). Control of mushroom sciarid fly *Lycoriella ingenua* (Dufour) with an azadirachtin-based insecticide. *Pesticidi i fitomedicina (Pesticides and Phytomedicine)*, **34**(2), 111–121. <https://doi.org/10.2298/PIF1902111D>.

PRECISION FEEDING: CRAFTING THE FUTURE OF POULTRY HEALTH, PRODUCTIVITY AND SUSTAINABLE GROWTH

Article ID: AG-VO5-I12-100***G. Karthikeyan¹, N. Kowsalya² and K. S. Sreyass³**¹Assistant professor, veterinary science, SRM College of Agricultural sciences, SRM University²Assistant professor, Poultry technology, College of Poultry Production and Management, Tamil Nadu veterinary and Animal Sciences University³Assistant professor, veterinary science, SRM college of Agricultural sciences, SRM University

*Corresponding Author Email ID: karthikg6@srmist.edu.in

Introduction

The poultry industry has seen remarkable growth in recent decades, driven by increasing global demand for poultry meat and eggs. In 2023, the global poultry market was valued at around \$322 billion, with expectations to grow at a compound annual growth rate (CAGR) of 4.8% through 2030, propelled by rising population, urbanization, and shifting dietary preferences towards high-protein foods. In India, the poultry market, valued at USD 28.18 billion, is projected to expand at a CAGR of 8.1% from 2024 to 2032, potentially reaching USD 44.97 billion by 2032. This growth underscores the crucial role of feed, which significantly impacts the health, productivity and overall performance of poultry.

Importance of feed in poultry growth

Feed represents the most substantial cost in poultry production, accounting for up to 70% of total production expenses. The quality and composition of poultry feed directly impact the growth rates, feed conversion ratios, health and overall productivity of the birds. Efficient feed utilization is crucial for achieving optimal performance and profitability in poultry farming.

Expected feed industry growth

The poultry feed industry is also set to expand in tandem with the growth of the poultry sector. In India, the poultry feed market reached a value of approximately USD 20,566.9 million in 2023. The market is further expected to grow at a CAGR of 7.29% between 2024 and 2032,

reaching a value of USD 31,489.4 million by 2032. The total poultry feed production in India stands at 22 million tonnes in 2023. This growth is driven by advancements in feed formulations, increased awareness of animal nutrition and the adoption of innovative feeding technologies.

Impact on poultry industry

The increasing scale of production demands more efficient and precise feeding strategies to ensure that the industry remains economically viable while meeting regulatory and consumer expectations. Traditional feeding methods often lead to overfeeding or underfeeding, resulting in wasted resources, higher costs and environmental pollution.

The need for precision feeding

Given the challenges and opportunities within the poultry industry, there is a pressing need for precision feeding both in the present and future. Precision feed involves the use of technology and data analytics to tailor nutrition programs to the specific needs of individual birds or flocks. This approach not only maximizes productivity and profitability but also addresses the industry's sustainability and animal welfare concerns.

What is Precision Feeding?

“Precision feeding ensures the right feed, in the right quantities, at the right time, for each individual bird”.

- Precision nutrition is the practice of adjusting and feeding diets to ensure the dietary nutrient supply equals the nutrient requirement of the animals daily.
- Precision feeding also allows diets to be adjusted in real-time; such fine diet control would be particularly effective in broiler production systems due to their extremely rapid growth.
- Precision feed involves the use of advanced technologies and data analytics to create customized feeding programs for poultry.
- It takes into account various factors such as the age, weight, health status and growth rate of the birds, ensuring they receive the optimal mix of nutrients at the right time.
- This essentially removes the under or over-feeding which is apparent in standard phase-feeding systems consisting of three to five diets.
- It also the ability to precisely measure the amount of feed delivered to chickens and hence accurately calculate feed intake and feed conversion ratio.

Essential steps for implementing precision nutrition in poultry

1. Accurate Ingredient Profiling,
2. Determining **Nutrient Requirements**,
3. Careful **Management**,

“Precision feeding is not just about optimizing feed efficiency; it’s about transforming poultry management through targeted nutrition and data-driven decisions.”

Recommendations for adopting precision feeding in poultry

1. Automatic Feeding System

Integrating automated feed distribution systems into logistics operations allows for precise delivery of the right amount of feed at the optimal time.

2. Centralized Feed Storage

On-site storage silos provide a centralized location for both feed ingredients and formulated feed. This setup ensures proper management and easy access to feed, reducing the risk of spoilage and contamination while maintaining feed quality.

3. Equipped Storage Silos

Storage silos within the farm complex should be equipped with weighing scales or feed weighing systems to accurately measure the amount of feed delivered to poultry and monitor remaining feed levels.

4. Customized Feed Formulation

Having an on-site feed mill enables the formulation of customized feed mixes that meet the specific nutritional needs of poultry. This flexibility allows for real-time adjustments based on data from precision feeding systems, optimizing growth rates and feed efficiency.

5. Streamlined Feed Delivery with Real-Time Monitoring

Implementing a coordinated logistics system with real-time monitoring and tracking ensures timely and accurate delivery of feed to poultry houses.

“By integrating these practices, poultry farms can enhance the effectiveness of precision feeding, resulting in better feed management, improved growth and productivity and more efficient operations”.

“Precision feeding allows us to move from one-size-fits-all approaches to customized nutrition, providing each bird with exactly what it needs for optimal growth and health.”

Precision feeding Vs Multiphase feeding

Both precision feeding and multiphase feeding aim to optimize the nutrition of poultry, but they do so at different levels of granularity. Multiphase feeding provides a more generalized approach by adjusting feed according to broad growth stages, such as using a specific starter feed for chicks and a different finisher feed for older birds. Precision feeding, on the other hand, takes this further by customizing feed at the individual bird level or for the flock in small intervals of time, such as on a daily basis, especially in broiler production.

Conclusion

Precision feeding is revolutionizing poultry farming by optimizing growth rates, improving feed efficiency, and enhancing animal welfare. This approach tailor's nutrition to each bird's needs, reducing waste and promoting sustainability. However, challenges such as high initial costs, technical complexity and data management must be addressed. As technology becomes more affordable and user-friendly, these barriers will diminish. Future advancements in data analytics, real-time monitoring and automation will further enhance precision feeding's impact, making it a key component in the future of efficient, sustainable and profitable poultry farming



Volume: 05 Issue No: 12

UNCONVENTIONAL CROPS UNDER POLYHOUSE: MARKET-LED OPPORTUNITIES FOR RAJASTHAN FARMERS

Article ID: AG-VO5-I12-101**Mr. Vishal Ghorela^{1*} and Dr. Seema Tyagi²**

¹Research Scholar, Institute of Agri Business Management, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan 334006 Email id- vishalghorela.iabm@gmail.com

² Assistant Professor, DPM&E, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan 334006, India

*Corresponding Author Email ID: seemavtyagi@yahoo.com

Introduction

In recent years, Rajasthan has witnessed a significant expansion in protected cultivation, particularly polyhouse farming, as farmers seek to overcome climatic constraints such as extreme temperatures, erratic rainfall, and declining water availability. Government initiatives under the Mission for Integrated Development of Horticulture (MIDH) and state horticulture schemes have accelerated adoption by offering capital subsidies ranging from 30 to 50 per cent of the total project cost. As a result, the area under polyhouse cultivation in Rajasthan has increased steadily, especially in districts such as Jaipur, Alwar, Sikar, Udaipur, and Jodhpur, where proximity to urban markets further supports commercialization (Government of India, 2023; National Horticulture Board, 2022).

According to estimates from the National Horticulture Board, Rajasthan has emerged as one of the leading states in protected cultivation in arid and semi-arid regions, with thousands of small and medium polyhouses established over the last decade. Year-wise trends indicate a sharp rise after 2016–17, coinciding with increased subsidy awareness and rising demand for off-season vegetables in urban centres (National Horticulture Board, 2022).

Dominance of Limited Crops under Polyhouse Systems

Despite the rapid spread of polyhouse technology, crop diversification within these structures remains limited. A large majority of polyhouse farmers in Rajasthan grow cucumber,

coloured capsicum, or tomato due to established production practices, availability of planting material, and relatively assured demand. Extension reports suggest that cucumber alone accounts for a dominant share of polyhouse cultivation because of its short crop cycle, ease of management, and familiarity among growers (Singh & Sharma, 2021).

However, this concentration on a narrow crop basket has led to periodic market gluts, price crashes, and reduced profitability, particularly during peak harvesting months when multiple growers supply the same produce simultaneously. Several studies have highlighted that while yields under polyhouse conditions are high, net returns often fluctuate due to market saturation rather than production inefficiencies (Singh & Sharma, 2021; Krishi Jagran, 2022).

Why Farmers Hesitate to Diversify Crops

One of the primary reasons for limited diversification is farmers' risk aversion. Polyhouse cultivation requires substantial initial investment, and farmers often prefer crops with proven production and marketing pathways to safeguard returns. Unfamiliar crops are perceived as risky due to uncertain demand, lack of price information, and absence of reliable buyers (Singh & Sharma, 2021).

Additionally, extension support and training programmes are largely oriented towards conventional polyhouse crops, reinforcing existing choices. Limited access to direct markets, dependence on middlemen, and inadequate branding of high-value niche produce further discourage experimentation with unconventional crops. As a result, technology adoption has outpaced market innovation, creating an imbalance between production potential and marketing strategies (FAO, 2013).

The Case for Market-Led Crop Diversification

To fully realize the economic potential of polyhouse farming, crop selection must be guided by market demand rather than production convenience alone. Rising urbanization, changing food habits, growth of the hospitality sector, and increasing health consciousness have created demand for exotic vegetables, medicinal herbs, and specialty crops that are not yet widely grown in Rajasthan (FAO, 2013).

Market-led diversification reduces price risk by targeting niche buyers such as hotels, cafés, pharmaceutical companies, and organized retailers. Polyhouse conditions are particularly suitable for such crops as they allow control over attributes like quality, uniformity, and residue levels, that are highly valued in premium markets (National Horticulture Board, 2022).

Unconventional High-Value Crop Options for Rajasthan Polyhouses

a) Exotic Leafy Vegetables

Leafy greens such as lettuce, arugula, kale, pak choi, and Swiss chard have significant potential under Rajasthan polyhouses. These crops require relatively low water, have short crop cycles of 30–40 days, and fetch premium prices due to limited local supply. Demand is driven by hotels, restaurants, cloud kitchens, and urban retail outlets, especially in cities like Jaipur and Udaipur (FAO, 2013; Krishi Jagran, 2023).

Under polyhouse conditions, consistent quality and year-round production are possible, enabling farmers to enter weekly or monthly supply contracts. Compared to cucumber, leafy greens offer faster cash turnover and better price realization per unit area, particularly when sold directly to institutional buyers (FAO, 2013).

b) Medicinal and Aromatic Crops

Medicinal and aromatic plants such as basil, chamomile, lemon balm, stevia, and ashwagandha present another promising diversification pathway. These crops are increasingly used by pharmaceutical, nutraceutical, and wellness industries, which prefer controlled cultivation to ensure uniform active ingredient content (FAO, 2013).

Polyhouse cultivation minimizes contamination and allows precise nutrient management, making it ideal for such crops. In Rajasthan, FPO-based models have shown success in linking growers with herbal product manufacturers, reducing marketing risk and improving income stability (National Horticulture Board, 2022).

c) Edible Flowers and Specialty Produce

Edible flowers such as rose petals, calendula, nasturtium, and lavender buds cater to niche but high-value markets including bakeries, luxury hotels, cosmetic brands, and Ayurveda-based enterprises. These crops require careful handling and quality control, both of which are facilitated by protected cultivation systems (FAO, 2013).

Although production volumes are low, price realization is significantly higher compared to conventional vegetables, making edible flowers suitable for small polyhouse units and peri-urban farmers targeting premium buyers (Krishi Jagran, 2023).

Farmer Mini Caselets from Rajasthan

a) Jaipur District: Transition from Cucumber to Exotic Greens

A polyhouse farmer from Chomu block in Jaipur district initially cultivated cucumber on a

1,000 sq. m polyhouse with MIDH subsidy support. Facing declining prices during peak season, the farmer diversified 30 per cent of the area into lettuce and basil for direct supply to cafés and restaurants in Jaipur city. The shift resulted in higher price realization and reduced dependence on mandi fluctuations, demonstrating the benefits of market-linked diversification (compiled from secondary sources and agri-media reports).

b) Udaipur Region: Medicinal Herbs through FPO Model

In the Udaipur region, an FPO facilitated collective cultivation of basil and chamomile under polyhouse conditions. With technical guidance from the horticulture department and assured procurement by a herbal products firm, farmers achieved better income stability compared to vegetable crops. The model highlights how institutional support and buyer linkage can mitigate risks associated with unconventional crops (National Horticulture Board, 2022).

Table 1: Comparative Price Table: Conventional vs Unconventional Polyhouse Crops

Crop Category	Average Price (₹/kg)	Crop Cycle (Days)	Key Buyers
Cucumber	25–35	45–50	Wholesale markets
Lettuce	60–85	30–35	Hotels, retail
Arugula	100–130	30–40	Cafés, premium stores
Basil	150–250	30–45	Pharma, wellness
Edible flowers	300–500+	45–60	Bakeries, cosmetics

Source: Compiled from secondary sources including FAO, National Horticulture Board, and agri-marketing reports

Conclusion

While polyhouse farming is expanding rapidly in Rajasthan, its full economic potential remains underutilized due to limited crop diversification. Shifting from production-driven decisions to a market-led approach can help farmers overcome price volatility and income uncertainty. Unconventional crops such as exotic leafy vegetables, medicinal herbs, and edible flowers offer viable alternatives, particularly when supported by institutional linkages and policy incentives. With strategic planning, Rajasthan's polyhouses can evolve from yield-maximizing

structures into engines of sustainable, market-oriented growth (FAO, 2013; National Horticulture Board, 2022).

References

- Food and Agriculture Organization of the United Nations. (2013). *Good agricultural practices for greenhouse vegetable crops: Principles for Mediterranean climate areas*. FAO Plant Production and Protection Paper No. 217.
- Government of India. (2023). *Mission for Integrated Development of Horticulture (MIDH): Operational guidelines*. Ministry of Agriculture & Farmers Welfare. <https://midh.gov.in>
- Krishi Jagran. (2022). *Rajasthan farmer earns higher income through polyhouse vegetable cultivation*. <https://krishijagran.com>
- Krishi Jagran. (2023). *Emerging trends in protected cultivation and high-value crops in India*. <https://krishijagran.com>
- National Horticulture Board. (2022). *Protected cultivation in India: Status and prospects*. Ministry of Agriculture & Farmers Welfare.
- Singh, B., & Sharma, R. (2021). Adoption and constraints of protected cultivation in arid and semi-arid regions of India. *Indian Journal of Agricultural Economics*, 76(3), 345–357.



Volume: 05 Issue No: 12

EMPOWERING RURAL WOMEN THROUGH MANGO PULP BOTTLING ENTERPRISE UNDER ARYA PROJECT

Article ID: AG-VO5-I12-102

**Snehalkumar A Patel*, Nital N. Patel, Kishore Makwana, Dikshita Prajapati and
Sumit Salunkhe**

Scientist, Krishi Vigyan Kendra, Navsari Agricultural University, Navsari-396450, India

*Corresponding Author Email ID: drsnehalkumarnau@gmail.com

Introduction

India is the world's largest producer of mango, accounting for nearly 45% of global mango production (NHB, 2023). Mango is often regarded as the “King of Fruits” due to its unique flavour, aroma and nutritive value. However, despite its importance, mango suffers from 25–30% post-harvest losses owing to poor handling, lack of processing and limited knowledge about preservation (ICAR-CISH, 2022). Value addition in mango, particularly mango pulp processing and bottling, offers immense potential to reduce post-harvest losses, extend shelf life and create livelihood opportunities for farmers and rural youth.



Pic 1: Training on Mango pulp bottling business under the ARYA project organized by KVK, NAU, Navsari

Recognizing the declining interest of rural youth in agriculture, the Indian Council of Agricultural Research (ICAR) launched the Attracting and Retaining Youth in Agriculture (ARYA) Project in 2016. The project aims to empower rural youth and women by introducing location-specific, income-generating and technologically sound enterprises. In Gujarat, the project is implemented through Krishi Vigyan Kendra (KVK) of Navsari Agricultural University (NAU), Navsari, Gujarat.

This success story highlights the entrepreneurial journey of Ms. Twinkle Jinalbhai Patel, a young woman farmer from Navsari district, Gujarat, who had received the training on mango pulp bottling business under the ARYA project organized by KVK, NAU, Navsari and started this enterprise.

Beneficiary Profile

Particulars	Details
Name	Ms. Twinkle Jinalbhai Patel
Age	27 years
Education	B. Com
Address	Street-Rupan Talav, At Post- Aat Ta- Jalapor, Di- Navsari
Landholding	4 Ha
Farming Experience	20 years
Crops Grown	Mango

Vulnerability and Problems Identified

Despite her long experience in farming, Smt. Twinkle faced several constraints in adopting mango pulp processing like lack of confidence and knowledge about adequate use of preservatives. Major technical issues like bottle bursting, discoloration and burning effects. Unawareness about safety, hygiene and microbial contamination risks. No prior use of brix meter, thermometer or other scientific tools. These gaps limited her ability to produce safe, quality and marketable mango pulp, resulting in low consumer trust.

Technological Interventions by KVK

KVK Navsari introduced simple but critical interventions to overcome these challenges:

- Use of new instruments such as brix meter, micro balance and thermometer to ensure accurate measurement of preservatives and processing temperature.

- Training on food safety, hygiene, microbial analysis and safe handling practices.
- Introduction of disinfectants, gloves, masks, hair caps, aprons and fire extinguishers to maintain safety and hygiene standards.
- Exposure through value addition conferences, farmer–scientist interactions and continuous supervision.



Pic 2: Young Farm woman Ms. Twinkle Mango pulp bottling enterprise

Efforts Made by KVK/Methodology Followed

The success was achieved through a systematic and participatory approach:

1. Identification of potential women entrepreneurs under ARYA project.
2. Skill-based training sessions on mango pulp processing.
3. Hands-on demonstrations of bottling techniques using scientific equipment.
4. Regular monitoring, mentoring and feedback support.
5. Encouragement for commercial-scale production and branding.

Outputs

- Increased awareness of hygiene, cleanliness and food safety precautions.
- Initiated microbial analysis of products to ensure consumer safety.
- Adoption of personal protective equipment (PPE) such as gloves, mask, hair cap and apron.
- Regular use of brix meter and thermometer for standardizing pulp quality.
- Enhanced consumer confidence due to improved product quality.

Outcomes

- Total 3000 mango pulp bottles prepared collectively by women entrepreneurs.
- Jagarutiben independently produced and sold 1000 bottles commercially.
- Product sold at ₹70 per bottle, generating ₹1,20,000 gross income.
- With an investment of ₹70,000, she earned a net profit of ₹50,000 in one season.
- KVK Navsari is now supporting branding and marketing initiatives for sustained income generation.

Economic Gains

Particulars	Value (₹)
Produce (bottles)	1000
Price per bottle	120
Gross Income	1,20,000
Cost of Production (70 Rs. Per Bottle)	70,000
Net Profit per Year	50,000

Discussion

The case of Ms. Twinkle highlights the significance of capacity building and technological interventions in transforming vulnerable rural women into confident entrepreneurs. While she initially faced challenges related to technical know-how and product safety, timely intervention by KVK enabled her to adopt scientific methods. The intervention not only generated substantial income but also built her confidence as a woman entrepreneur, Enhanced consumer trust due to safe and hygienic products, created a replicable model for other farmers in Navsari district, Contributed towards the national goal of doubling farmers' income through value addition.

Conclusion

The ARYA Mango Pulp Bottling initiative in KVK, Navsari stands as a model success story of women empowerment, skill development and agri-entrepreneurship. With the guidance of Scientists of KVK, Navsari, Smt. Twinkle Patel not only achieved economic independence but also inspired several other rural women to take up fruit processing as a sustainable livelihood option.

References

1. ICAR (2016). *Attracting and Retaining Youth in Agriculture (ARYA) Project Guidelines*. Indian Council of Agricultural Research, New Delhi.
2. ICAR-CISH (2022). *Annual Report 2021–22*. ICAR-Central Institute for Subtropical Horticulture, Lucknow.
3. NHB (2023). *Indian Horticulture Database 2023*. National Horticulture Board, Ministry of Agriculture and Farmers Welfare, Government of India.



Volume: 05 Issue No: 12

ROLE OF FRONT-LINE DEMONSTRATIONS IN ENHANCING ADOPTION OF IMPROVED AGRICULTURAL TECHNOLOGIES IN BUNDELKHAND REGION

Article ID: AG-VO5-I12-103**Saurabh Shukla*¹ and Sakshi Chaturvedi²**

1 PhD Research Scholar, Department of Agricultural Economics, Institute of Agricultural Sciences, Bundelkhand University Jhansi Uttar Pradesh India

2 Young Professional-II, Indian Grassland and Fodder Research Institute (IGFRI), Jhansi, Uttar Pradesh, India

*Corresponding Author Email ID: saurabhanilshukla@gmail.com

Abstract

The Bundelkhand area of Uttar Pradesh is characterized by fragile Agro-ecological conditions, erratic rainfall, and heavy dependence on rainfed agriculture, thus constraining crop productivity and farm income together. FLDs, as carried out through ICAR–Krishi Vigyan Kendra’s (KVKs), are an effective extension mechanism for demonstrating improved agricultural technologies in location-specific farmers' field conditions. This study assesses the role of FLDs in enhancing the adoption of improved crop production technologies and evaluates the performance gap between the FLD and non-FLD farmers in Bundelkhand during 2022–2024. The major crops covered include chickpea, mustard, groundnut, wheat, and pea regarding yield, economic returns, and technology adoption parameters. The results show that the yields from the FLD plots have been 18 to 32 percent higher outputs with significantly more favourable benefit-cost ratios over the farmers' conventional practices. Demonstrations also promoted better adoption of improved varieties, balanced nutrient management, and integrated pest management practices. The findings suggest that the FLDs play a pivotal role in reducing the technology gaps, enhancing farm profitability, and bolstering the farmers' confidence, thus contributing toward sustainable agricultural development in the Bundelkhand region.

Key words: FLD, Bundelkhand, technology adoption, FLD versus Non-FLD, crop productivity, farm income.

1. Introduction

Bundelkhand includes the southern part of Uttar Pradesh and is one of India's most vulnerable agricultural regions due to frequent droughts, shallow and degraded soils, low water holding capacity, and marked climatic variability. Agriculture is mainly rainfed in nature, and farming is dominated by small and marginal farmers who adopt few improved technologies and therefore face low productivity and erratic incomes.

The gulf between agricultural research and field-level adoption remains particularly wide in such stress-prone contexts. Against this background, the Indian Council of Agricultural Research (ICAR) has institutionalized FLDs within its network of KVKs. Demonstration of newly released varieties of crops and improved production technologies is done through FLDs, which are conducted directly in farmers' fields under real farming conditions. Through participatory learning and direct observation, FLDs build confidence among farmers in scientific technologies and encourage broader adoption.

2. Materials and Methods

Selected districts of the Bundelkhand region - namely, Jhansi, Lalitpur, and Jalaun - were taken for investigation covering the period of 2022-2024. Data from FLD plots laid down by Krishi Vigyan Kendra and from contiguous non-FLD farmers following conventional practices were collected.

The main crops focused on in the research were:

- Chickpea
- Mustard
- Groundnut
- Wheat

- Pea The FLD plots followed recommended standard packages of practices by the ICAR, whereas the prevailing farmers' practices were reflected in non-FLD plots. A comparative analysis for yield, cost of cultivation, gross return, net return, and benefit–cost ratio was done.

3. Results and Discussion

3.1 Crop-wise Coverage of FLDs

The table indicates that FLDs were primarily concentrated on major rabi and oilseed crops, reflecting their importance in the regional cropping system and livelihood security.

Table 1. Crop-wise FLD Coverage in Bundelkhand (2022–24)

Crop	Improved Variety	No. of FLDs	Area (ha)
Chickpea	JG 14	120	48
Mustard	Pusa Mustard 25	95	38
Groundnut	TG 37A	70	35
Wheat	HD 3226	110	55
Pea	IPFD 10-12	60	30

Source: ICAR–KVK Annual Progress Reports (2022–24)

3.2 Yield Performance: FLD vs non-FLD

Table 2. Yield Comparison between FLD and Non-FLD Farmers

Crop	Non-FLD Yield (q/ha)	FLD Yield (q/ha)	Yield Increase (%)
Chickpea	12.5	16.2	29.6
Mustard	10.8	14.0	29.6
Groundnut	14.0	18.5	32.1
Wheat	32.0	38.0	18.8
Pea	9.5	12.3	29.5

Source: Field data from KVK Jhansi, Lalitpur & Jalaun (2022–24)

The results clearly demonstrate the superiority of FLD plots over non-FLD farmers' practices. Yield enhancement was primarily due to the adoption of improved varieties, timely sowing, recommended seed rates, balanced fertilizer application, and integrated pest management.

3.3 Economic Analysis

Table 3. Economics of FLD and Non-FLD Crops (₹/ha)

Crop	Practice	Cost of Cultivation	Gross Return	Net Return	B:C Ratio
Chickpea	Non-FLD	32,000	56,250	24,250	1.76
	FLD	34,500	72,900	38,400	2.11
Mustard	Non-FLD	30,000	54,000	24,000	1.80
	FLD	32,000	70,000	38,000	2.19

Crop	Practice	Cost of Cultivation	Gross Return	Net Return	B:C Ratio
Groundnut	Non-FLD	45,000	70,000	25,000	1.56
	FLD	48,000	92,500	44,500	1.93

Source: Directorate of Agriculture, Uttar Pradesh; KVK records.

FLD plots generated substantially higher net returns despite slightly higher input costs, indicating better resource-use efficiency and economic viability of improved technologies.

3.4 Technology Adoption: FLD vs non-FLD

Parameter	Non-FLD Farmers	FLD Farmers
Variety	Local / obsolete	Improved HYVs
Seed treatment	Negligible	Widely adopted
Nutrient management	Imbalanced	Soil test-based
Pest management	Chemical dependent	IPM-based
Yield stability	Low	High

FLDs significantly improved awareness and adoption of scientific practices, with noticeable spillover effects among neighbouring farmers.

4. Constraints Observed

Although positive results were recorded, the study identified the following constraints in FLDs during the observation period:

- Irregular rainfall and recurring moisture stress, especially during critical stages of land phenology
- Limited availability and timely access to quality seeds and other essential inputs
- Small, fragmented landholdings that constrain mechanization and scale economies
- Inadequate farm mechanization and reliance on traditional tools
- Restricted access to institutional credit, hence constraining investment by farmers in improved inputs and technologies Weak market linkages and price volatility constrain full realization of income despite increased production under FLDs.

5. Impact of Front-Line Demonstrations

FLDs conducted in the Bundelkhand region have exhibited a multidimensional influence on crop productivity, farm profitability, and farmers' behavioural responses to improved agricultural technologies.

I. Impact on Crop Productivity

In general, FLD demonstrations resulted in a yield increase of about 18–32 percent over non-FLD farming methods in major crops. The reasons for such yield enhancement were mainly the adoption of high-yielding and stress-tolerant varieties, timely sowing, appropriate seed rate, proper nutrient management, and best crop management practices demonstrated under the different FLDs. Better initial crop establishment along with reduced biotic and abiotic stresses contributed to higher yield stability, especially under rainfed conditions.

II. Impact on Farm Income and Profitability

The economic analysis revealed that net farm income was significantly higher – ₹12,000–20,000 per hectare – from the FLD plots compared to non-FLD plots. While cultivation costs under FLDs were marginally higher on account of the use of quality inputs and enhanced practices, the increase in gross returns outweighed the additional costs. The FLD plots resulted in higher benefit–cost ratios, showing better input-use efficiency and enhanced profitability.

III. Impact on Technology Adoption

FLDs considerably enhanced farmers' awareness and adoption of improved agricultural technologies. A greater proportion of FLD participants adopted the use of improved varieties, seed treatment, soil-test-based fertilizer application, and integrated pest management practices. The demonstrations also spurred a shift from calendar-based to need-based crop management thereby reducing excessive input use and production risk.

IV. Spillover and Extension Impact

One of the key impacts of FLDs was the strong spillover effect generated among neighbouring non-FLD farmers. Regular field days, training sessions, and farmer–scientist interactions during the demonstration period motivated non-participating farmers to adopt demonstrated technologies in subsequent seasons. This horizontal diffusion of technology multiplied the extension impact of FLDs beyond the immediate beneficiary group.

V. Impact on Farmers' Confidence and Decision-Making

Participation in FLDs helped develop farmers' confidence in scientific recommendations and decision-making capabilities. Farmers were more willing to invest in quality inputs and adopt risk-mitigating practices such as seed treatment and balanced fertilization. The resulting better crop performance under FLDs strengthened farmers' resilience to climatic uncertainties and reduced reliance on traditional trial-and-error approaches.

6. Conclusion and Way Forward

The present study has revealed that FLDs have played a pivotal role in enhancing the adoption of improved agricultural technologies in the Bundelkhand region. Comparisons of FLD and non-FLD farmers show that crop productivity, profitability, and technology adoption were significantly higher under FLD conditions. Yield increases of around 18 to 32 percent, coupled with sizeable increases in net farm income, underline the potentiality of FLDs as a farmer-centric extension modality in stress-prone, rainfed areas like Bundelkhand.

Beyond yield and income benefits, FLDs have been substantially instrumental in enhancing farmers' knowledge, skills, and confidence in scientific crop management practices. Improved variety adoption, seed treatment, soil-test-based nutrient management, and integrated pest management were considerably higher among FLD participants. The strong spillover effects of these amongst the neighbouring farmers further underscore the role of FLDs in accelerating the horizontal dissemination of technologies and closing the research-extension-farmer gap.

The study, however, points out the imperative of intensifying the implementation of FLDs by overcoming region-specific constraints in climatic variability, access to quality inputs, institutional credit, and market linkages. Scaling up FLD coverage, especially for small and marginal farmers, and convergence of extension efforts with irrigation, mechanization, and crop insurance programs will add to their impact.

Going forward, FLDs should focus on promoting climate resilient crop varieties, water-use-efficient technologies, precision nutrient management, and digital advisory services, all matched to the local agroecological conditions. This is coupled with enhanced farmer–scientist interaction, farmer-led demonstrations, and integration of FLDs with market-oriented interventions related to value addition and assured procurement for effectively contributing to sustainable agricultural development and ensuring livelihood security in Bundelkhand.

References

- ICAR (2023). *Annual Reports of Krishi Vigyan Kendras*. New Delhi.
- DAC&FW (2024). *Agricultural Statistics at a Glance*. Government of India.
- NITI Aayog (2022). *Bundelkhand Region Development Report*.
- Directorate of Agriculture, Uttar Pradesh (2023). *District Agricultural Statistics*.
- KVK Jhansi, Lalitpur & Jalaun (2022–24). *FLD Progress Reports*.

Volume: 05 Issue No: 12

SUCCESS STORY ON REINVENTING RURAL LIVELIHOODS THROUGH SCIENTIFIC LIVESTOCK MANAGEMENT

Article ID: AG-VO5-I12-104

Budharam^{1*}, Gopichand Singh², Rakesh gurjar³, H.R. Choudhary⁴, Bhawana Sharma⁵ and Kalpana Choudhary⁶

¹Subject Matter Specialist (Animal husbandry), ²Senior Scientist & Head,

³Senior Research Fellow, ⁴Subject Matter Specialist (Agronomy),

⁵Subject Matter Specialist (Home science) and ⁶Subject Matter Specialist (Horticulture),
Krishi Vigyan Kendra, Athiyasan, Nagaur-I, Agriculture University, Jodhpur (Rajasthan), India

*Corresponding Author Email ID: jat.97ram@gmail.com

Introduction

Name of farmer	Shri Prema Ram	
Father's Name	Ramdeen Jhalwaniya	
Age	42 yr	
Mobile	+91-9783329907	
Address	Village- Role, Tehsil: Jayel, District: Nagaur, Rajasthan	
Land holdings (Rainfed)	10 Acres Rainfed	
Livestock Unit	Goat unit (Sirohi & Sojat Breeds)	

Occupation: **Sustainable Goat Farming in Arid Rajasthan**

From Traditional Farming to Scientific Livestock Enterprise

Shri **Prema Ram**, a progressive farmer from the drought-prone village of **Role** in **Jayel Tehsil**, Nagaur, has transformed his livelihood by adopting **scientific goat farming**, water conservation, and improved fodder management with the guidance of the **Krishi Vigyan Kendra (KVK)**, Nagaur.

Facing the challenges of uncertain rainfall and low returns from traditional crop farming, he decided to diversify into **commercial goat rearing**, aligning with government support schemes and modern technologies.

Role of KVK & Government Support

KVK Nagaur provided vocational training on “Scientific Goat Farming and Fodder Management” which included- Goat breeds and breed selection, Housing and shelter management, Feeding, mineral nutrition, and fodder planning, Health care, vaccination, and disease management, Record keeping and marketing strategies and technical guidance and field-level support from KVK, Nagaur, and under the National Livestock Mission (NLM), Prema Ram took several key initiatives:



Capacity building training for Goat rearing



Napier Grass (CO-5)



Goat Farming Unit (Sirohi & Sojat Breeds)

1. Goat Farming Unit (Sirohi & Sojat Breeds):

- Established a scientifically managed goat farm with **300 goats** of **Sirohi and Sojat** breeds.

- Regular deworming, vaccination, and hygiene practices adopted.
- Shed design and space management followed standard recommendations.

2. Farm Pond Construction:

- Constructed a **Farm Pond** on his 10-acre land to harvest rainwater.
- Ensured year-round water availability for both crops and livestock.
- Improved sustainability and reduced dependency on erratic monsoon.

3. Green Fodder Demonstration – Napier Grass (CO-5):

- Introduced and cultivated **CO-5 Napier grass** as part of a KVK demonstration.
- Ensured **continuous supply of nutritious green fodder** for goats.
- Increased milk yield and improved weight gain in animals.

4. Mineral Mixture Supplementation:

- Adopted regular use of **mineral mixture** in animal feed.
- Addressed issues of infertility, weak bones, and slow growth.
- Enhanced overall animal health, productivity, and immunity.

Economic & Social Impact

Annual Income: ₹10–12 lakhs from goat farming alone.

Employment: Provided local employment opportunities for youth.

Fodder Security: Year-round green fodder through CO-5 Napier.

Healthy Herd: Low mortality and better reproductive performance.

Recognition: Acknowledged by KVK Nagaur as a **Model Livestock Farmer**.

Celebration with KVK – A Moment of Pride

To celebrate his success and inspire fellow farmers, Prema Ram organized a **farm-level interaction program** in collaboration with **KVK Nagaur**. The event was attended by:

- KVK Scientists and Extension Officers
- Local Veterinary Officials
- Fellow Farmers from nearby villages

During the program, he showcased his **goat unit**, **Napier grass plot**, and **farm pond**. KVK experts shared technical insights on livestock care, fodder planning, and the benefits of balanced nutrition using mineral mixtures.

The event served as a **live demonstration site** and an **inspiration** for other small and marginal farmers.



Message from the Farmer

“With proper planning, scientific methods, and the support of KVK and government schemes, even small farmers like me can achieve big success. Goat farming, when done right, is a goldmine for dryland regions like ours.” - **Shri Prema Ram**



CLIMATE CHANGE AND FRUIT PRODUCTION: CHALLENGES AND OPPORTUNITIES

Article ID: AG-VO5-I12-105***Vasanth S¹ and Arul Prasad S²**

¹ Ph. D scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, HC&RI,
TNAU, Coimbatore.

² Teaching Assistant, Department of Agro climatic research Centre, TNAU, Coimbatore-641003, India.

*Corresponding Author Email ID: vasanths1506@gmail.com

Introduction

Climate change isn't just a headline -it's a lived reality for farmers around the world. From apples in Washington to mangoes in India, fruit growers are confronting hotter temperatures, unpredictable rainfall, shifting seasons, and new pests. At the same time, this era of environmental change has sparked innovation, resilience, and an urgent focus on sustainable agriculture.

In this article, we explore how climate change affects fruit crops -from flowering to fruit set, quality, and yield -and what farmers are doing to adapt. We'll separate myth from science, highlight real-world responses, and uncover hopeful opportunities for the future.

Understanding the Climate Puzzle: More Than Just "It's Hotter"

Climate change means more than rising temperatures. It includes:

- Increasing average temperatures
- Greater temperature extremes
- Shifts in rainfall timing and intensity
- Longer or shorter growing seasons
- More frequent droughts and floods
- Changing patterns of pests and diseases

For fruit producers, these changes influence every stage of growth -from bud break to harvest. While fruit trees are rooted in place and can't escape stress, farmers can often

respond with knowledge, technology, and innovation.

Flowering: The First Vulnerable Step

Why Flowering Matters

Flowering is a critical stage -without flowers, there's no fruit. Timing and duration of flowering are finely tuned to climate conditions.

Impact of Climate on Flowering

1. Warmer Winters and Chill Requirements

Many fruit trees -especially temperate fruits like apples, cherries, peaches, and pears -require a period of cold during winter to break dormancy and produce flowers. This “chill requirement” ensures synchronized bud burst and a full, productive bloom.

With warming winters:

- Some regions no longer provide enough chilling.
- Trees may have delayed or uneven flowering.
- Flower quality can decline.

Farmers in traditionally cool areas now find that their trees act as if spring got confused -buds emerge slowly or not at all, reducing fruit set.

2. Early Spring Warming

If temperatures rise too early in spring:

- Buds may break early.
- A late frost can then damage fragile flowers.
- Result: significant loss of potential fruit.

This pattern -early warmth followed by frost -has become more frequent in many fruit-growing regions.

3. Heat Stress During Bloom

Excessive heat during bloom can:

- Reduce pollen viability.
- Alter flower physiology.
- Lower pollination success.

Fruit Set: When Nature Decides How Many Fruits Stay

“Fruit set” refers to the transition from flower to actual fruit. Not all flowers become fruit -nature prunes for efficiency. But climate stress can worsen fruit drop.

Stressful Weather = Weaker Fruit Set

- High temperatures can desiccate young ovaries.
- Humidity shifts affect pollinator activity.
- Heavy rains can wash pollen off flowers.
- Drought stress forces trees to abort fruit to conserve water.

Fruit Quality: More Than Just Bigger and Brighter

Fruit quality matters for taste, storage, shipping, and consumer satisfaction. Climate change influences:

1. Size and Appearance

- Heat can accelerate maturation, causing smaller fruits.
- Frost or hail can damage skin.
- Temperature swings can create irregular shapes.

2. Sugar Content and Flavor

Temperature affects carbohydrate metabolism:

- Warm nights can increase sugar accumulation.
- Heat stress can reduce acidity, dulling flavor.
- Cold nights can slow sugar build-up.

Climate change often brings warmer nights, which may alter fruit flavor profiles -sometimes improving sweetness, but often at the expense of balance.

3. Texture

Heat waves can:

- Cause sunburn on fruit surfaces.
- Increase internal breakdown.
- Affect firmness -crucial for shipping.

4. Nutritional Value

Emerging research indicates climate stress can alter vitamin and antioxidant content, though patterns vary by species.

Below the Surface: Climate Effects on Trees' Physiology

Climate change doesn't just affect the visible parts of the plant; it affects the whole system:

- Water balance: High temperatures increase evaporation and plant transpiration.
- Root development: Soil moisture extremes hurt fine root growth.

- Carbohydrate reserves: Heat and drought force trees to use stored sugars for survival, leaving less for growth and fruiting.
- Phenology shifts: Overall life cycle timing changes -trees may leaf out earlier, pushing them out of sync with beneficial timing windows.

Pests and Diseases: A Rising Threat Under a Changing Climate

One of the most profound effects of climate change is on pest and disease dynamics:

Warmer Winters - More Survivors

Cold winter temperatures historically controlled insect and pathogen populations. Milder winters mean:

- More insects survive to reproduce.
- Some insect life cycles speed up.
- New pest species move into previously unsuitable areas.

Examples include increased mite pressure in orchards or expanded ranges of fruit flies and codling moths.

Humidity and Disease Pressure

Climate change alters moisture conditions:

- More humidity = fungal diseases like powdery mildew and brown rot.
- Drier conditions = some bacterial diseases become more aggressive.

Farmers now face a shifting threat landscape, requiring updated management strategies.

Water: The Heart of the Climate Challenge

Water is life for agriculture -and climate change is altering both supply and demand.

Droughts and Scarcity

Many fruit regions are experiencing:

- Less predictable rainfall.
- Lower river flows.
- Groundwater depletion.

Fruit crops - especially in dry climates -demand reliable water. Drought stress reduces flowering, fruit set, and quality.

Floods and Too Much Water

Flooding can:

- Suffocate roots due to lack of oxygen.

- Encourage root-rot diseases.
- Leach nutrients from soil.

Both extremes -drought and flood -cause yield losses.

The Opportunities Within the Crisis

While the challenges are serious, farmers and scientists are innovating. Here's what's happening on the ground.

Adaptation Strategies Farmers Are Using

1. Changing Cultivars and Species

Growers are planting:

- Heat-tolerant varieties
- Lower chill requirement cultivars
- Drought-resistant rootstocks

Breeders are shifting priorities to climate resilience, not just yield or taste.

2. Adjusting Planting Zones

In some countries, fruit production zones are migrating poleward or to higher elevations as climates warm. Regions once unsuitable for certain fruits are becoming viable.

3. Improved Water Management

Farmers are investing in:

- Drip irrigation and micro-sprinklers for precise water delivery.
- Soil moisture sensors to avoid over/under-watering.
- Rainwater harvesting and storage systems.
- Mulching to conserve soil moisture.

These techniques help stretch limited water resources and buffer drought impacts.

4. Protective Structures

Greenhouses, shade nets, and high tunnels help control microclimates:

- Shade nets reduce heat stress and sunburn.
- High tunnels protect blossoms from rain and hail.
- Controlled environments improve uniformity and quality.

5. Altering Pruning and Training Practices

Pruning timing and techniques are adapting -for example:

- Delaying pruning to avoid early bud break before frost risk is gone.

- Training trees in shapes that reduce heat damage or improve air flow.

These are low-cost, high-impact adjustments.

6. Integrated Pest and Disease Management (IPM)

To stay ahead of pests:

- Farmers monitor pest populations.
- Use traps and biological controls.
- Rotate pesticides judiciously.
- Adopt forecasting tools that track climate and pest activity.

Digital tools that predict pest outbreaks based on weather help reduce chemical use and increase yields.

7. Adjusting Harvest Timing

Farmers are refining harvest windows as fruit maturation rates change. Some fruits ripen earlier; others develop unevenly. Testing fruit maturity with sugar and firmness measurements helps optimize timing.

Technology and Digital Tools: New Allies for Growers

Emerging technologies offer major leverage:

Remote Sensing and Drones

These tools help farmers:

- Monitor tree health across large acreage.
- Detect stress before symptoms show.
- Precisely apply water, nutrients, or pest control.

Climate Modelling Tools

Agricultural climate models help predict:

- Future chill hours
- Frost risk periods
- Optimal planting dates
- Pest/disease risk windows

Growers use these insights to make informed decisions.

AI and Data Analytics

Digital platforms integrate weather, soil, and plant data to:

- Forecast irrigation needs

- Flag disease risks
- Optimize fertilizer use
- Improve overall efficiency

Community and Policy Responses

Farmers are not acting alone. Governments, researchers, companies, and NGOs are stepping in:

1. Research Investment

Public and private investments fund:

- Climate-resilient breeding
- Disease-resistance research
- Water-use efficiency innovations

2. Extension Services and Education

Agricultural extension officers train farmers in:

- New irrigation methods
- Pest monitoring
- Climate-adapted practices

3. Insurance and Risk Management

Weather and crop insurance schemes help farmers absorb losses from extreme events.

4. Sustainable Certification and Market Incentives

Consumers increasingly value sustainable agriculture. Certifications that reward climate-smart practices can create market premiums for farmers.

A Word About Carbon and Sustainability

Fruit trees are part of the climate solution:

- Orchards sequester carbon in biomass and soil.
- Permanent tree crops support biodiversity.
- Agroforestry systems combine fruit trees with other crops for ecosystem benefits.

However, fruit production also has emissions:

- Energy for irrigation and cooling
- Fertilizer production and application
- Food miles from farm to plate

Balancing production with sustainability is key.

Real Stories from the Orchard

To bring this into sharper focus, consider these illustrative examples:

Apples in Northeastern U.S.

Growers once relied on long, cold winters for chill hours. Warmer winters have led to erratic blooms, forcing shifts to new chill-tolerant cultivars and increased use of shade and frost protection.

Citrus in the Mediterranean

Rising temperatures and drought stress have plagued citrus growers. Innovative irrigation and drought-tolerant rootstocks are helping save water and maintain yields.

Mangoes in South Asia

Unpredictable monsoons and extreme heat have complicated flowering and fruit set. Farmers are adopting mulching, water harvesting, and early-maturing varieties to cope.

Across these regions, farmers share a blend of worry and determination -but also creativity.

Looking Ahead: What the Future Holds

Climate models project continued warming and increased climate variability. For fruit agriculture, this means:

- More pressure on heat and water management
- Evolving pest and disease landscapes
- Potential new growing areas
- Greater reliance on science and technology

Yet fruit farming has always adapted to change -from early cultivation thousands of years ago to modern sustainable solutions.

The future of fruit production won't look like the past -but it can be robust, productive, and resilient if we combine traditional wisdom with innovation.

Conclusion

Climate change poses real and complex challenges for fruit production. From flowering disruptions to quality issues and emerging pests, growers face a changing environment that demands flexibility, knowledge, and new tools. But in challenge lies opportunity. Adaptation strategies -from improved water management to advanced climate forecasting -are helping growers thrive. With continued research, supportive policy, and sustainable practices, fruit communities worldwide can nourish consumers while building resilience.

CROSS-TALK BETWEEN BIOCHEMICAL PATHWAYS IN CROP PLANTS

Article ID: AG-VO5-I12-106

Dr. M. Shanmuganthan*

Professor (PBG), Department of Genetics and Plant Breeding

Agricultural College and Research Institute, Kudumiyamalai – 622 104, Tamil Nadu

*Corresponding Author Email ID: shanmuganathan.m@tnau.ac.in

Introduction

The cross-talk between biochemical pathways refers to the complex system of communication, coordination and interaction between different biochemical pathways so that plants can optimize growth, development, defense and stress responses. It ensures that pathways do not work in isolation but influence each other through shared metabolites, signaling molecules and regulatory networks. This integrated network allows the plant cell to create a unified, dynamic and effective biological response to various internal and external stimuli, especially during crucial developmental stages and under environmental stress.

Why cross-talk between biochemical pathways is so important in crops?

Understanding this cross-talk is the key to unlocking the next generation of crop improvement. It's the difference between seeing a plant as a collection of parts and seeing it as an integrated, responsive system.

- 1. Resource efficiency and yield:** The ultimate goal for most crops is high yield (e.g., more grain, more fruit). This requires a perfect balance between capturing energy (photosynthesis) and using that energy to build valuable molecules like starch, protein and oils. Cross-talk ensures that carbon from photosynthesis is efficiently allocated to the developing grain.
- 2. Stress resilience:** Crops constantly face challenges like drought, salinity, extreme temperatures and pathogen attacks. Cross-talk allows a plant to mount a coordinated defense. For example, a drought signal can trigger changes in metabolism that conserve water while also priming the plant's defense against pathogens that might invade through drought-stressed tissue.

3. **Balancing growth and defense:** This is a classic trade-off. A plant has a finite amount of energy. Investing heavily in growth can leave it vulnerable to pests, while investing heavily in defense can stunt its growth and reduce yield. Cross-talk, mediated by hormones and other signals, helps the plant find the right balance based on its environment.
4. **Nutritional quality:** The nutritional value of a crop (e.g., protein content in wheat, oil composition in soybeans, or vitamin content in corn) is determined by which metabolic pathways are active. Cross-talk influences the flow of carbon and nitrogen into these different nutritional compounds.

Cross-talk between biochemical pathways in crop plants

Cross-talk refers to the interactions and communication between different biochemical and signaling pathways within plant cells. This coordination ensures efficient resource use, balanced growth and appropriate responses to environmental cues. Here's how cross-talk happens between major pathways in crop plants:

1. Cross-talk between primary metabolic pathways

Primary metabolism includes photosynthesis, respiration, nitrogen metabolism, lipid metabolism and carbohydrate metabolism.

a) Photosynthesis ↔ Respiration

- Photosynthesis produces sugars → used in respiration.
- Respiration provides ATP + NADH needed for photosynthesis (Calvin cycle regeneration).

Example:

During high light, excess photosynthates activate glycolysis & TCA cycle to balance energy.

b) Photosynthesis ↔ Nitrogen metabolism

- N assimilation (nitrate → ammonium → amino acids) requires energy from photosynthesis (ATP + NADPH).
- Amino acid synthesis provides nitrogenous compounds for chlorophyll and protein formation.

Key interacting nodes:

- Glutamine synthetase (GS)
- Glutamate synthase (GOGAT)

c) Carbon (C) Metabolism ↔ Nitrogen (N) Metabolism

This is the most fundamental cross-talk in any plant.

- **The pathways: Photosynthesis** (Carbon fixation) produces sugars (carbon skeletons). **Nitrogen assimilation** uses these carbon skeletons to incorporate inorganic nitrogen (from the soil) into amino acids, the building blocks of protein.

The cross - talk

- **Carbon for Nitrogen:** You can't make amino acids without carbon. A key metabolite, **2-oxoglutarate**, from the respiratory pathway (which breaks down sugars), is a direct acceptor for ammonia during nitrogen assimilation. If photosynthesis is low, there aren't enough carbon skeletons, and nitrogen uptake stops.
- **Nitrogen for Carbon:** The availability of nitrogen acts as a signal. High nitrogen can stimulate photosynthesis, signaling the plant to produce more energy to use that nitrogen. Low nitrogen can down-regulate photosynthetic genes to conserve resources.
- **Crop Relevance:** This balance directly determines the **protein content of grains**. Breeders aim for varieties that can efficiently take up nitrogen and convert it into grain protein without sacrificing overall yield.

d) Carbohydrate ↔ Lipid Metabolism

- Excess sugars → converted to lipids (in oilseeds: soybean, groundnut, sunflower).
- Lipid breakdown during germination feeds into glycolysis & TCA cycle.

Example:

Triacylglycerol → acetyl-CoA → energy for seedling growth.

2. Cross-talk between primary and secondary metabolism

Secondary metabolites include phenolics, flavonoids, alkaloids, terpenoids, phytoalexins.

- **The pathways: Primary metabolism** includes pathways essential for survival (photosynthesis, respiration). **Secondary metabolism** produces compounds that are not essential for basic survival but provide a competitive advantage (e.g., pigments for UV protection, toxins for pest defense, and compounds for flavor and aroma).
- **The cross-talk:** Secondary metabolism is a "branch" off primary metabolism. It uses the precursors and energy (ATP) generated by primary metabolism.

Example (Phenylpropanoids): The amino acid **phenylalanine** (from primary metabolism) is the starting point for a huge family of secondary compounds called

phenylpropanoids. These include **lignin** (for structural strength), **flavonoids** (for UV protection and flower color) and **tannins** (for defense against herbivores).

- **Resource allocation:** When a plant is attacked by a pest, it will divert carbon from the phenylalanine pool away from growth-related processes and towards the production of defensive flavonoids or toxins.

- Stress-induced cross-talk:

Under drought, salinity:

- Sugars signal production of phenolics & antioxidants.
- Amino acid pools shift toward proline (osmoprotectant).

Example: JA (jasmonic acid) induces alkaloids; SA (salicylic acid) induces phenolics.

Crop Relevance: This cross-talk **determines** a crop's **natural pest resistance** and its **nutritional quality**. Many of the antioxidants and vitamins we value in fruits and vegetables (e.g., anthocyanins in blueberries, lycopene in tomatoes) are secondary metabolites.

3. Hormonal Cross-Talk Connecting Pathways

Sugars are not just food; they are powerful signaling molecules that communicate the plant's energy status and regulate development.

- **The Pathways: Sugar signaling** pathways (e.g., involving trehalose-6-phosphate) sense glucose and sucrose levels. **Hormone pathways** involve auxin (growth), cytokinin (cell division), and abscisic acid (ABA - stress response).

The Cross-Talk

- **High sugar:** High sugar levels **promote** growth by interacting with auxin and cytokinin signaling pathways. The plant "knows" it has enough energy to invest in new leaves, stems, and roots.
- **Low sugar or stress:** During drought, the plant produces the stress hormone **ABA**. ABA signaling can inhibit photosynthesis and growth, conserving water. It also interacts with sugar signaling to ensure the limited energy is prioritized for survival, not growth.
- **Crop relevance:** Manipulating this cross-talk is a major goal. For example, scientists are trying to create rice varieties that maintain high grain yields even under drought by altering the interaction between sugar and ABA signaling pathways.

4. Cross-talk in signaling pathways

Biochemical pathways interact via:

- Reactive oxygen species (ROS)
- Calcium signaling
- Protein kinases (MAPKs)
- Redox signals
- Sugar signaling (trehalose-6-phosphate, sucrose)

This integration coordinates:

- Growth
- Stress tolerance
- Development (flowering, germination, senescence)

5. Cross-talk under environmental stresses

Heat Stress

- Increases respiration → reduces photosynthesis
- Enhances production of heat-shock proteins (secondary metabolism)

Drought Stress

- ABA interacts with carbohydrate metabolism → stomatal closure
- Enhances proline & antioxidant pathways

Nutrient Deficiency

- N deficiency → increases flavonoid production
- P deficiency → cross-talk with lipid remodeling (phospholipids → glycolipids)

6. Cross-talk relevant to crop improvement

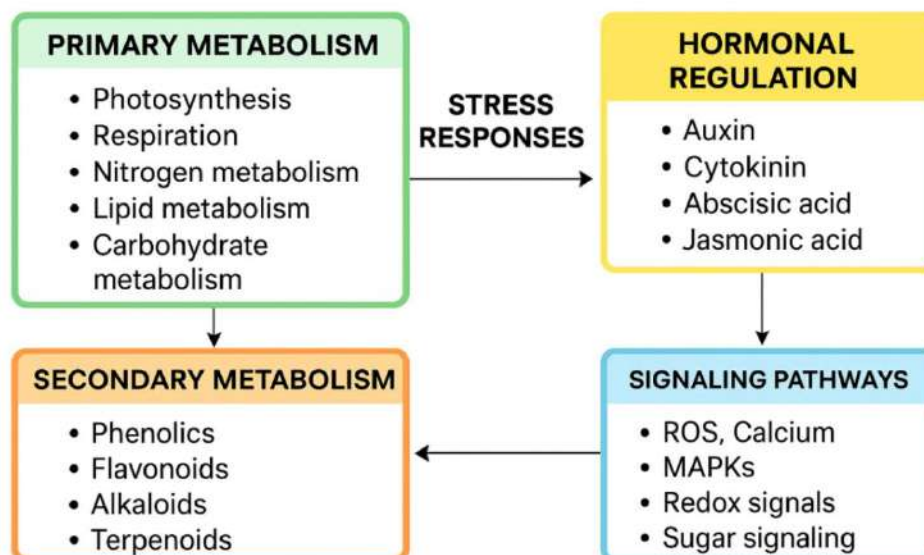
Plant breeders use knowledge of cross-talk to enhance:

- Nitrogen use efficiency
- Stress tolerance (drought/salinity/heat)
- Yield and biomass
- Disease resistance

Transgenic strategies target:

- Carbon fixation pathways
- Hormone signaling (ABA, SA, JA)
- ROS-scavenging enzymes
- Secondary metabolic pathways

CROSS-TALK BETWEEN BIOCHEMICAL PATHWAYS IN CROP PLANTS



How we study and use this knowledge

Understanding this complex network is a massive challenge, but new technologies are making it possible.

1. **"Omics" technologies:** Genomics, transcriptomics, proteomics and especially **metabolomics** (the study of all metabolites in a cell) allow scientists to get a snapshot of the entire network. They can see how hundreds of pathways change simultaneously in response to a stress or during grain filling.
2. **Genetic engineering & breeding:** By identifying "hub" genes or regulators that control multiple pathways, scientists can create crops with desirable traits.
Example: A gene might be found that increases the flow of carbon from leaves to grain *without* triggering the plant's defense mechanisms that would otherwise reduce yield. This is a classic case of fine-tuning cross-talk.
3. **Synthetic biology:** In the future, we may be able to design entirely new, more efficient pathways that bypass natural regulatory bottlenecks, creating "super-crops" with unprecedented yields or nutritional profiles.

Mechanisms facilitating cross-talk

Biochemical pathways interact through various mechanisms, including:

- Shared components: Two pathways may use the same enzyme or metabolite as an intermediate. The flow of this shared component can regulate both pathways.
 - *Example:* The competition for a common precursor between the glucosinolate pathway and the phenylpropanoid pathway in *Arabidopsis* (a model for crops) affects the production of defense compounds and structural components like lignin.
- Transcriptional regulation: A signaling molecule or transcription factor activated by one pathway can regulate the expression of genes encoding enzymes in a different pathway, either activating or inhibiting them.
- Post-translational modification (PTMs): Enzymes or regulatory proteins in one pathway can be modified (e.g., phosphorylated, ubiquitinated) by components (like kinases or ligases) from another pathway, changing their activity or stability.
- Hormonal interactions (Signaling cross-talk): Phytohormones often form a complex regulatory network where one hormone's signaling cascade can synergize with or antagonize another's, coordinating the plant's response.
- Compartmental transport: Movement of metabolites between chloroplasts, mitochondria, cytosol ensures integrated functioning.
- Regulatory proteins and transcription factors: These regulate multiple genes across pathways, coordinating their activities.

Roles of cross-talk between biochemical pathways in crop physiology and stress response

Cross-talk is critical for optimizing growth and survival, making it a key area for improving crop yield and resilience.

1. Coordinating growth and development

- Carbon-Nitrogen (C/N) Metabolism: Pathways for carbohydrate synthesis (Carbon) and amino acid/protein synthesis (Nitrogen) are tightly linked. The C/N status of the plant dictates the partitioning of resources into storage reserves (like starch, lipids, and proteins) in seeds, a major determinant of crop yield and quality.
- Hormone-nutrient signaling: The signaling pathway for a nutrient like nitrate interacts extensively with phytohormones (e.g., auxins, cytokinins) to modify the root system architecture, allowing the plant to better forage for nutrients in the soil.

2. Integrating stress responses

Plants in the field often face multiple simultaneous stresses (e.g., heat and drought). Cross-talk allows for an integrated, rather than an isolated, defense strategy.

Stressor(s)	Key pathways interacting	Type of cross-talk	Outcome for the crop
Biotic Stress (Pathogens)	Salicylic Acid (SA) and Jasmonic Acid (JA) / Ethylene (ET) signaling	Antagonistic / Synergistic	Defense against pathogens (e.g., SA for biotrophic, JA/ET for necrotrophic)
Abiotic Stress (Drought/Cold/Salt)	Absciscic Acid (ABA) signaling and Reactive Oxygen Species (ROS) metabolism	Cooperative	Stomatal closure to prevent water loss (ABA), activation of antioxidant defenses (ROS)
Combined Stresses	Multiple hormone pathways (ABA, SA, JA) and cellular metabolism	Integrated network	Prioritization of limited resources to mitigate the most immediate or severe combined threat.

Understanding these points of cross-talk offers opportunities for metabolic engineering and breeding strategies to improve crop performance by subtly modulating the activity of one pathway to benefit an interconnected one.

Summary

Cross-talk in crop plants integrates primary (C, N, energy) and secondary metabolism with hormonal and environmental signaling. It ensures balanced resource allocation between growth and defense, enabling plants to survive stresses while maintaining productivity. Understanding pathway cross-talk helps in designing crops with improved metabolic efficiency, yield, photosynthesis, biomass, nutrient use efficiency and stress tolerance.

IMPACT OF PHARMACEUTICALS IN MARINE ENVIRONMENT

Article ID: AG-VO5-I12-107**A. Yamini^{1*}, D. Manimekalai² and S. Sakthi³**

^{1,2,3}Fisheries University, Fisheries College and Research Institute, Thoothukudi, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam, Tamil Nadu, India

*Corresponding Author Email ID: yaminiys25@gmail.com

Abstract

Pharmaceuticals are chemically diverse compounds widely used in human and veterinary medicine, increasingly detected in aquatic environments due to extensive consumption and incomplete removal during wastewater treatment. They enter marine systems through sewage discharge, aquaculture, animal husbandry, horticulture, and improper waste disposal. Once released, pharmaceuticals undergo transformation, adsorption to sediments, and bioaccumulation, with their fate influenced by marine conditions such as salinity and pH. Exposure to these contaminants causes physiological stress, endocrine disruption, reproductive impairment, and behavioural alterations in marine organisms. Even at low concentrations, pharmaceuticals pose ecological risks, highlighting the need for improved management and pollution mitigation strategies.

Keywords: Pharmaceuticals, sewage, bioaccumulation

Introduction

Pharmaceuticals are synthesised or derived from natural inorganic or organic chemical compounds and are used for the prevention and treatment of diseases. These compounds are often used for diagnosis in humans and animals as well as improving their quality of living. Pharmaceuticals differ in terms of their structure and behaviour, their applications, their metabolism in animals and humans as well as their effect in the environment. The occurrence of pharmaceuticals and their transformation products in the environment has become a subject of growing interest due to their impact on living organisms, including human health, as well as the

increasing amounts of these compounds that are introduced into the environment. The presence of pharmaceuticals and their transformation products was observed in surface and ground waters, drinking water, bottom sediments, soils, wastewater and sewage sludge, as well as in animals and edible plants.

Types of Pharmaceuticals

Pharmaceuticals can be broadly classified based on their therapeutic use, chemical nature and mode of action. Therapeutically, they include analgesics that relieve pain, antipyretics that reduce fever, antibiotics and antivirals that fight bacterial and viral infections respectively, and antifungals that target fungal diseases. Other categories include antihypertensives for controlling blood pressure, antidiabetics for managing blood sugar, anticancer drugs for treating tumors, anti-inflammatory medications, cardiovascular drugs for heart conditions, and psychotropic drugs that affect mood and behavior. Chemically, pharmaceuticals may be small-molecule drugs, biologics derived from living organisms, peptide-based drugs, or nucleic acid-based therapies like mRNA vaccines. In terms of mode of action, they can act as enzyme inhibitors, receptor agonists or antagonists, ion channel modulators, or hormone regulators. Understanding the types and effects of pharmaceuticals is therefore crucial for assessing their environmental impact and for developing effective strategies for water treatment and pollution mitigation.

Sources of pharmaceuticals

1) Sewage

Sewage effluent is a key source of pharmaceuticals entering aquatic environments, with removal efficiencies in wastewater treatment plants varying widely depending on drug properties and treatment methods. Pharmaceuticals originate from community use, hospitals, manufacturing discharges, and maritime activities, and reach marine waters through WWTP outfalls, rivers, sewer overflows, ships, and boats. Poorly managed septic systems and sewage-contaminated groundwater further contribute to coastal contamination, making sewage a widespread and significant pathway for pharmaceutical pollution in aquatic ecosystems.

2) Aquaculture

Global seafood production from aquaculture is rapidly expanding, with over 90% occurring in Asia, where veterinary medicines, including antibiotics also used in human healthcare, are widely applied to prevent and control diseases. A substantial proportion of these drugs—up to 75% of the administered dose—can be released into the surrounding environment

through uneaten feed, excretion of unmetabolized drugs and metabolites, and farm effluents. These pharmaceuticals may further spread as wild organisms consume leftover feed and waste. Coastal pond-based aquaculture and wastewater-fed farming practices, still present in parts of Asia, can discharge high levels of antibiotics into nearby waters, with exceptionally elevated concentrations reported in some shrimp farms. Overall, variations in aquaculture practices and antibiotic use among countries make aquaculture a significant and uneven source of pharmaceutical contamination in aquatic environments.

3) Animal husbandry and horticulture

Animal husbandry and horticulture near rivers and coastal areas also contribute to pharmaceutical inputs into aquatic systems. Antibiotics are commonly used in animal feeds and drinking water, especially in intensive livestock operations, and low-dose use as growth promoters persists in some regions despite bans in Europe. In horticulture, certain antibiotics are permitted for crop protection in some countries. Additionally, the application of municipal biosolids as fertilizers introduces pharmaceuticals into agricultural soils, from where they can be transported to nearby surface and coastal waters through runoff and leaching.

4) Waste disposal

Waste disposal in coastal areas is a further source of pharmaceuticals entering the marine environment. Leachate from coastal landfills and seafills may be a pathway for pharmaceuticals disposed of in household and clinical wastes to enter coastal waters. Landfill leachate on the island of Mallorca contained up to 27 000 ng l⁻¹ total concentration of pharmaceuticals [26]. Historically, in some regions drug manufacturing waste, sewage sludge and animal manure were dumped at sea.



Fate of pharmaceuticals in marine environment

Once released into aquatic environments, pharmaceuticals and their metabolites undergo biotic and abiotic transformation, can adsorb to suspended particles and sediments, and may accumulate in aquatic organisms. Their environmental fate differs between freshwater and marine systems due to variations in salinity, pH, organic matter, and light availability. In seawater, higher pH can alter the behavior of ionizable pharmaceuticals, while reduced light penetration may limit photodegradation compared to freshwater. As a result, pharmaceuticals can exhibit different stability and transformation patterns in marine environments, with some compounds showing greater persistence in seawater than in freshwater.

Effect on marine organisms

1. Physiological and Biochemical Effects

Many pharmaceuticals interfere with normal physiological processes:

Non-steroidal anti-inflammatory drugs (NSAIDs) such as diclofenac and ibuprofen induce oxidative stress, lipid peroxidation, and tissue damage in fish and bivalves. Antibiotics disrupt mitochondrial function and enzyme activity, affecting energy metabolism. Alteration of detoxification enzymes (e.g., cytochrome P450) impairs the organism's ability to process other pollutants.

2. Endocrine Disruption and Reproductive Effects

Hormonal pharmaceuticals and endocrine-active compounds are among the most ecologically concerning:

- Synthetic estrogens (e.g., 17 α -ethinylestradiol) cause feminization, intersex conditions, and reduced sperm quality in fish. Altered hormone signaling affects gonadal development, spawning success, and larval survival. In invertebrates, pharmaceuticals disrupt molting and reproductive cycles 744.

3. Behavioural Alterations

Neuroactive pharmaceuticals significantly affect marine organism behavior:

- Antidepressants (e.g., fluoxetine, sertraline) alter feeding, aggression, predator avoidance, and swimming activity in fish and crustaceans. Behavioral changes increase predation risk and reduce foraging efficiency. Even without causing mortality, these changes have serious ecological consequences.

Case study: Impact of diclofenac on marine mussels

A case study by Aguirre-Martínez et al. (2015) investigated the effects of the widely used anti-inflammatory drug diclofenac on the marine mussel *Mytilus galloprovincialis*. Diclofenac commonly enters coastal waters through treated and untreated wastewater discharges and is frequently detected at low concentrations in marine environments. In this study, mussels were exposed under laboratory conditions to environmentally relevant concentrations of diclofenac to assess sublethal biological responses. The results showed a significant increase in oxidative stress, evidenced by altered antioxidant enzyme activities and enhanced lipid peroxidation, indicating cellular damage. In addition, DNA strand breaks were observed in mussel tissues, demonstrating genotoxic effects even in the absence of mortality. Diclofenac exposure also impaired immune function by reducing hemocyte viability and phagocytic activity. These findings highlight that chronic exposure to pharmaceutical residues can compromise the physiological health of marine bivalves, potentially affecting their survival, reproduction, and ecological role. This case study underscores the importance of using filter-feeding organisms as bioindicators to evaluate the ecological risks of pharmaceutical contamination in marine ecosystems.

Conclusion

Pharmaceuticals enter marine environments through multiple anthropogenic sources and persist due to incomplete removal and slow degradation. Once present, they can accumulate in sediments and organisms, causing physiological, reproductive, and behavioral disturbances. Even at low concentrations, these compounds produce sublethal effects that threaten marine biodiversity and ecosystem stability. Continuous inputs increase the risk of long-term ecological impacts. Effective management and improved treatment strategies are therefore urgently required.

References

- Aguirre-Martínez, G. V., Buratti, S., Fabbri, E., & DelValls, T. A. (2015). *Diclofenac exposure induces oxidative stress, genotoxicity and immunological alterations in the marine mussel Mytilus galloprovincialis*. Environmental Pollution, 206, 211–220.
- Gaw, S., Thomas, K.V. and Hutchinson, T.H., 2014. Sources, impacts and trends of pharmaceuticals in the marine and coastal environment. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1656), p.20130572.

- Gworek, B., Kijeńska, M., Zaborowska, M., Wrzosek, J., Tokarz, L. and Chmielewski, J., 2020. Occurrence of pharmaceuticals in aquatic environment—a review. *Desalination and Water Treatment*, 184, pp.375-387.
- us der Beek, T., Weber, F.A., Bergmann, A., Hickmann, S., Ebert, I., Hein, A. and Küster, A., 2016. Pharmaceuticals in the environment—Global occurrences and perspectives. *Environmental toxicology and chemistry*, 35(4), pp.823-835.



Volume: 05 Issue No: 12

NON-THERMAL PROCESSING TECHNOLOGIES IN FOOD PROCESSING INDUSTRIES

Article ID: AG-VO5-I12-108**Aswathy T and Ravindra Naik***

ICAR Central Institute of Agricultural Engineering, Regional Station,
Coimbatore- 641 007, Tamil Nadu, India

*Corresponding Author Email ID: naikravindra@gmail.com

Introduction

Food processing and preservation technologies primarily focus on extending the shelf life by inactivating enzymes and microorganisms; however, it is equally important to ensure that the product's quality is maintained. Conventional food preservation processes such as pasteurization, sterilization, drying and evaporation involve subjecting foods to high-temperature treatments that are capable of destroying microorganisms, but they may also cause some undesirable changes in the food. The thermal techniques used for preservation results in the formation of chemical toxicants and also observable changes in the food. Non-thermal technologies have emerged as a promising solution to address these concerns (Safwa *et al.*, 2023). These technologies have minimal impact on nutrients, flavors, colours and other sensory attributes.

Non-thermal technologies help inactivate microorganisms and enzymes, thereby extending the shelf life of food while better preserving its quality, flavor, color and nutritional value compared to conventional thermal processing methods.

Types of non-thermal processing technologies

- 1) Ultrasonication
- 2) High Pressure Processing (HPP)
- 3) Pulsed Electric Field (PEF)
- 4) Irradiation
- 5) Pulsed ultraviolet technology

- 6) Cold plasma technology
- 7) Ozone Treatment

Ultrasonication:

It is an emerging non-thermal and non-destructive green technology in the food sector. Ultrasound is a sound wave having higher frequency of above 20kHz, which is more than the normal human hearing frequency. As ultrasonic waves pass through a medium, they create repeated compression and expansion cycles that form small air-filled cavities. These cavities grow and eventually collapse, releasing high energy and producing localized hot spots, which enhance heat and mass transfer rates and which can inactivate microorganisms (Bhangu *et al.*, 2016). It has many applications such as filtration, freezing, drying, thawing, sterilization and extraction.

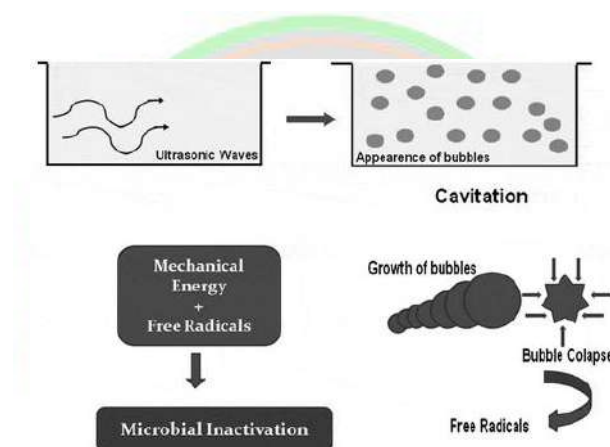


Figure 1. Cavitation phenomenon and microbial inactivation by ultrasonic waves (Majid *et al.*, 2015)

High Pressure Processing (HPP):

Food processing technology which applies high pressure (400-600 MPa) to solid or liquid foods to improve their safety and, in some cases, enhances their organoleptic properties and overall quality. Packaging should be vacuum packs or other flexible packaging. It is also called high hydrostatic pressure processing. Foods are placed into a specially designed pressure chamber which is sealed and completely filled with potable water, then pressurized using this water. Food is subjected to high pressure for a short duration of time.

HHP can substantially reduce the population of gram-positive and gram-negative bacteria, as well as yeasts and molds, thereby contributing to extended food preservation. This reduction depends on the temperature and pressure during treatment (Jadhav *et al.*, 2021). Its applications are pasteurization, freezing, thawing and sterilization.

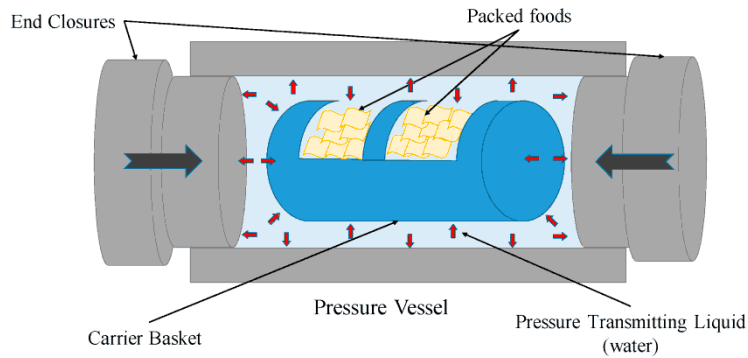


Figure 2. Schematic representation of high pressure processing (HPP) vessel (Balakrishna *et al.*, 2020)

Pulsed Electric Field (PEF):

It is an emerging non-thermal technology that operates by applying brief pulses of high electric fields, lasting from microseconds to milliseconds, with electric field strength typically ranging from 10 to 80 kV/cm. In this method, the food is placed between a pair of electrodes, and pulsed electrical current is applied, generating an electric charge that ultimately leading to the destruction of microorganisms. PEF will preserve the nutritional aspects of food. It has numerous applications in dairy industry, fruits and vegetables industry, meat industry, seafood industry and egg industry (Safwa *et al.*, 2023).

Irradiation:

Food irradiation is a preservation technique that uses ionizing radiation to destroy bacteria, molds and insects thereby enhancing food safety and extending shelf life without making the product radioactive. This ‘cold’ process uses energy from gamma rays, electron beams, or X-rays to deactivate microbes, prevent sprouting and slow down ripening. It is suitable for many types of foods such as meats, fruits, vegetables and spices and generally does not cause notable changes in colour, aroma or flavor.

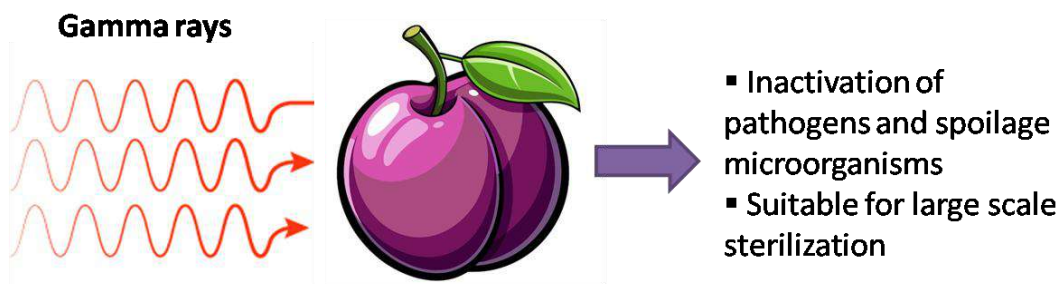


Figure 3. Schematic representation of Irradiation

Pulsed ultraviolet technology:

It is a economical, non-thermal technology, basically used to reduce the microbial load on the surface of food materials that are indirectly exposed to radiation. When food is treated, the short wavelengths are absorbed by the nucleic acids of microbial cells. The absorbed photons disrupt the genetic material of the microbes, and leading to the cell malfunction and death (Guerrero-Beltrán *et al.*, 2021).

Cold plasma technology:

Plasma, the fourth state of matter, is a highly energized and unique form of matter. Based on thermodynamics, plasma can be classified into two primary types; thermal plasma and low-temperature plasma.

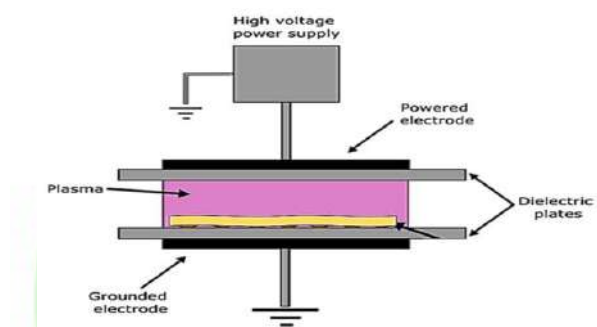


Figure 4. Schematic diagram of Dielectric Barrier Discharge (DBD) for CP treatment (Perera, *et al.*, 2022)

In thermal plasma, the temperature is extremely high, whereas low-temperature plasma will have low temperature and also known as ‘cold plasma’ or non-thermal plasma. Cold plasmas are generated using various configuration systems, such as dielectric barrier discharges (DBD), and plasma jets. In these systems, the feed gas is energized into plasma, which plays a significant role in microbial decontamination, making it a valuable tool for food preservation (Safwa *et al.*, 2023). Cold plasma has applications in pasteurization, seed germination, inactivation of microorganisms, drying and thawing.

Ozone treatment:

Ozone (O_3) is a colourless gas with a characteristic odor and is widely used as an effective antibacterial agent in food systems. It can be applied either in gaseous form or as ozonated water. Ozone inactivates microorganisms by disrupting cell membrane integrity, altering membrane permeability, and damaging protein structures. This leads to enzyme malfunction, impaired metabolic activity, and ultimately microbial cell death. Its applications in

food processing include inactivation of spoilage microorganisms, inactivation of toxins present in food, and disinfection of processing equipment etc.

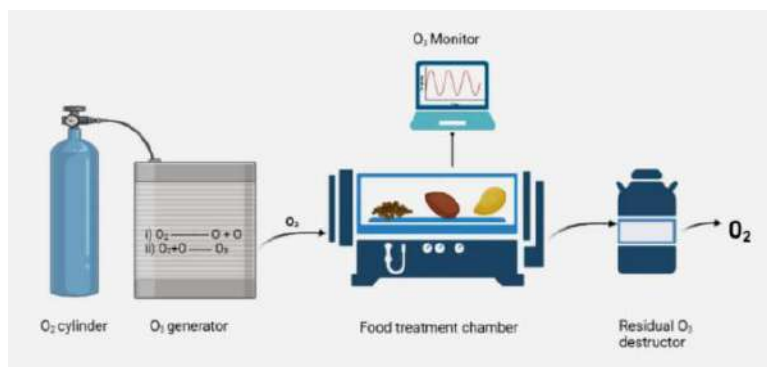
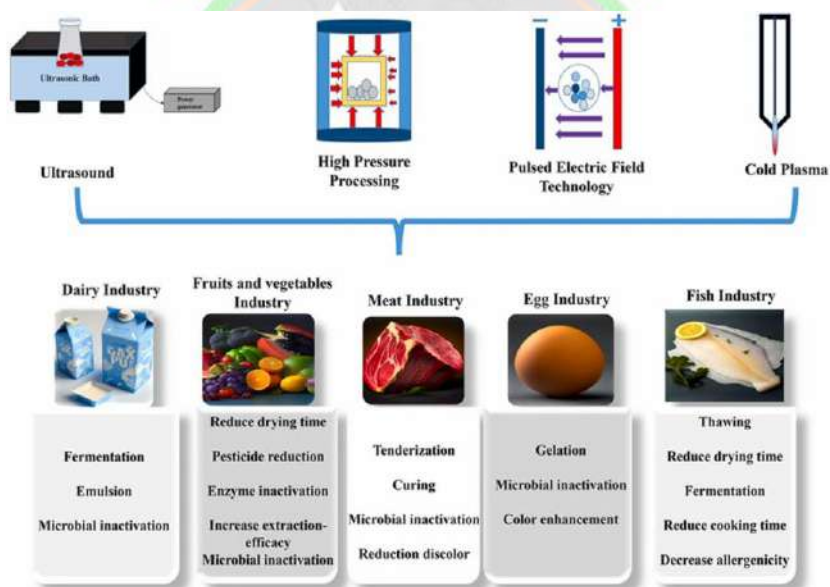


Figure 5. Ozone treatment food preservation technique (Source: <https://microbenotes.com/ozone-treatment-as-a-food-preservation-technique/>)

Applications of non-thermal processing technologies in various food industries



(Source: Safwa *et al.*, 2023)

Advantages of non-thermal processing

- Retains nutritional and sensory qualities:** These methods help to preserve the freshness, flavor, color, and nutritional content of food more effectively than traditional heat-based processes.
- Minimal impact on enzymes and proteins:** Non-thermal methods can inactivate enzymes and microorganisms without denaturing proteins or causing significant changes to the food's structure.

- ✚ **Extended shelf life:** Non- thermal processing can extends the shelf life of products by deactivating spoilage-causing microorganisms.

Conclusion

Nowadays, along with food preservation, maintaining the quality also becomes a major concern. Non-thermal processing technologies are better than heat-based processing methods. These techniques requires short period of exposure and can be treated at ambient temperature. Hence, there is less chance of food damage and quality degradation. This also has adverse effects when food products are exposed for a longer period or treated at a higher intensity may lead to some undesirable changes in food. The larger scale applications of these technologies are challenging. Additionally, development of equipments for non-thermal processing, understanding the mechanisms, development of processing standards, and clarifying consumer myths and misunderstanding about these technologies will be helpful for the upliftment of non-thermal technologies in the food sector. Once these limitations are overcome, non-thermal technologies can expand their development and commercialization in the food industry, providing consumers with safe, nutritious foods with good colour and mouthfeel.

References

- Balakrishna, A. K., Wazed, M. A., & Farid, M. (2020). A review on the effect of high pressure processing (HPP) on gelatinization and infusion of nutrients. *Molecules*, 25(10), 2369. <https://doi.org/10.3390/molecules25102369> ★ ★
- Bhangu, S. K., & Ashokkumar, M. (2016). Theory of sonochemistry. *Sonochemistry: From Basic Principles to Innovative Applications*, 1-28.
- Guerrero-Beltrán JÁ, Ochoa-Velasco CE. Ultraviolet-C light technology and systems for preservation of fruit juices and beverages. In: Knoerzer K, Muthukumarappan K, editors. *Innovative Food Processing Technologies*. Voctoria (2021). p. 210–26. doi: 10.1016/B978-0-08-100596-5.22937-5
- Jadhav, H. B., Annapure, U. S., & Deshmukh, R. R. (2021). Non-thermal technologies for food processing. *Frontiers in Nutrition*, 8, 657090.
- Majid, I., Nayik, G. A., & Nanda, V. (2015). Ultrasonication and food technology: A review. *Cogent Food & Agriculture*, 1(1). <https://doi.org/10.1080/23311932.2015.1071022>



- Oner, M. E., & Demirci, A. (2016). Ozone for food decontamination: Theory and applications. In *Handbook of hygiene control in the food industry* (pp. 491-501). Woodhead Publishing. <https://doi.org/10.1016/B978-0-08-100155-4.00033-9>
- Perera, K. Y., Prendeville, J., Jaiswal, A. K., & Jaiswal, S. (2022). Cold plasma technology in food packaging. *Coatings*, 12(12), 1896. <https://doi.org/10.3390/coatings12121896>
- Safwa, S. M., Ahmed, T., Talukder, S., Sarkar, A., & Rana, M. R. (2024). Applications of non-thermal technologies in food processing Industries-A review. *Journal of Agriculture and Food Research*, 18, 100917.

NET ZERO AND CIRCULAR ECONOMY APPROACHES IN THE FOOD PROCESSING SECTOR

Article ID: AG-VO5-I12-109**Anjana K and Ravindra Naik***

ICAR Central Institute of Agricultural Engineering, Regional Station, Coimbatore- 641 007,
Tamil Nadu, India

*Corresponding Author Email ID: naikravindra@gmail.com

Introduction

Globally, 13.2 per cent of food is lost in the supply chain after harvest and before reaching to the retail markets, and 19 per cent more is wasted at the retail, food service and household levels (UNEP statistics, [2024](#)). In earlier days, people were least concerned about the exploitation of natural resources, as they were easily available and cheap. As food production increased with increasing demand due to population escalation, the waste produced also increased. This has led people and governing bodies to recognize the harmful effects of food waste on the environment. As per Consultative Group on International Agricultural Research (CGIAR), consumption of energy is significantly higher in food processing sector responsible for climate change. Approximately 19-29% of global annual greenhouse gas emissions are caused by the food processing sectors, which utilize about 30% of world's energy production.

Food loss and waste is a major concern in the present scenario. A huge amount of food waste is being produced on a daily basis. This food loss and waste is the major challenge faced during the sustainable food system design. According to FAO, food loss and waste leads to an estimated 8 to 10 per cent of global greenhouse gas emissions and it also have negative impacts on food security and nutrition. Moreover it fuels biodiversity loss, degradation of natural ecosystems, environmental pollution etc. These challenges have made the adoption of sustainable practices in the food processing sector increasingly crucial. The sustainable practices play an important role in ensuring long-term food security, reducing resource depletion, and protecting human and environmental health.

Sustainability in the food processing industry mainly relies on two major approaches, Net Zero and the Circular Economy. Both aim to reduce environmental impact, improve resource efficiency, and ensure long-term viability of food systems.

What is circular economy in food system?

Circular economy focuses on minimizing the waste while maximizing the utilization. Instead of use and throw habit, circular economy aims sustainability, longevity, reuse and recycling. The circular economy offers a transformative approach to the food industry by promoting environmental health, human well-being, and economic prosperity. It also provides a broad opportunity to circulate resources and waste in a closed loop network.

In other terms, circular economy in food system is a set of systematic practices and principles which reform food production, **distribution** and consumption and transform linear food chains into regenerative, circular systems. The main principles of circular economy are:

1. Reduce

- Optimize production processes to use fewer raw materials, water, and energy.
- Develop efficient technologies to extend shelf life and reduce spoilage.

2. Reuse

- Reuse packaging materials where safe and feasible.
- Repurpose by-products internally (e.g., using heat recovered from processes).

3. Recycle

- Convert unavoidable food waste into valuable resources such as compost, animal feed, biofuels, or bioplastics.

4. Recover.

- Capture energy from residues through anaerobic digestion or biomass conversion.

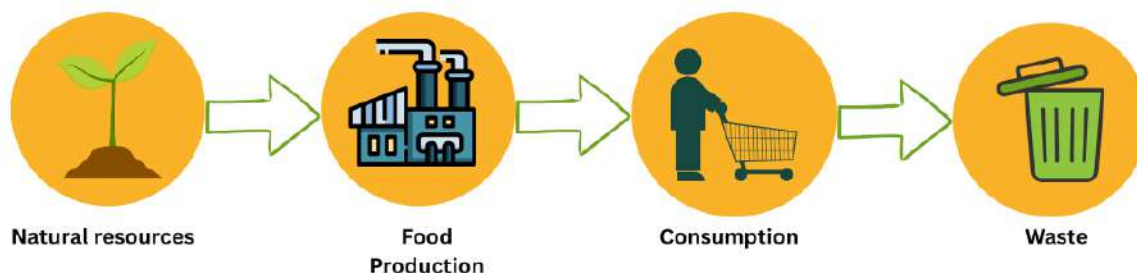


Figure 1. Diagrammatic representation of linear economy in food system

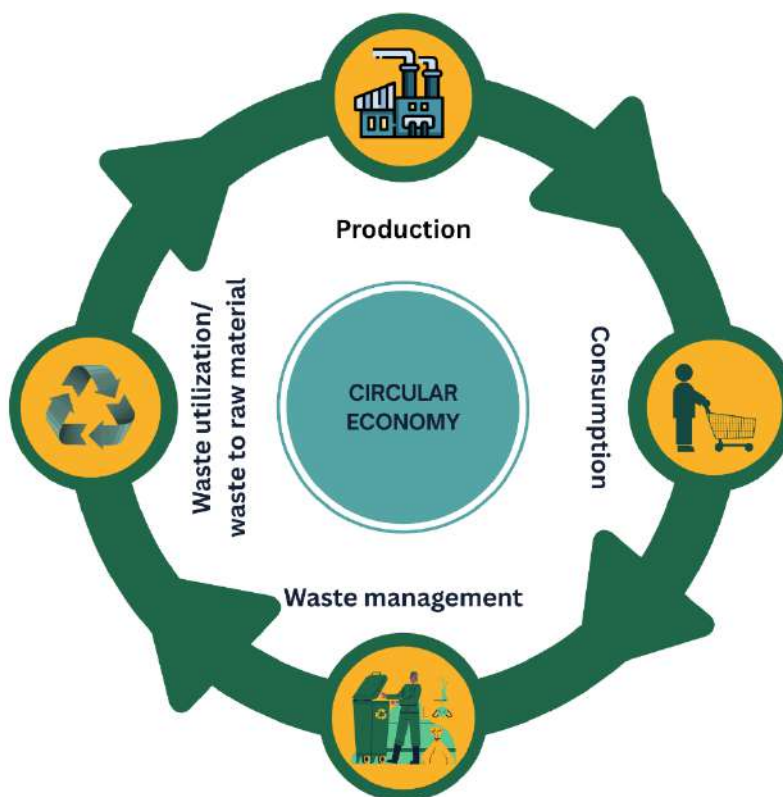


Figure 2. Diagrammatic representation of circular economy in food system

Valorization of By-products

One of the most impressive features of a circular food system is its ability to turn by-products into valuable resources. Thus valorisation of by-products is a main component of circular economy implementation. Most of the food processing activities results in a huge amount of waste in terms of organic residues, which are typically discarded under the linear models. Circular system encourages the utilization of these discarded residues as resources for some other industries. By-products from the fruits and vegetable industries can be used to extract bio active compounds, natural colorants, natural flavours, fibres or pectin. Dairy whey can be processed into protein isolates and nutraceutical ingredients. These valorisation process not only eliminates waste and environmental pollution but also create additional income.

Sustainable Packaging

Packaging is an important challenge in the food processing industry since it causes a large amount of waste especially plastic. Principles of circular economy encourages the utilization of recyclable, compostable, or bio-based packaging materials. It also emphasizes the need of redesigning of products and supply chains to reduce packaging needs. Dependency on

single-use plastics are being reduced by the intervention of reusable and refillable packaging systems. Such innovations require coordinated efforts across manufacturers, retailers, and consumers to ensure system-wide effectiveness

Energy Recovery and Resource Efficiency

Energy recovery from unavoidable organic waste is another important dimension of circular economy. Technologies such as anaerobic digestion, gasification, and fermentation enable the conversion of food residues into biogas, bioethanol, or other bioenergy products. Integrating these systems into processing plants can reduce fossil fuel consumption and contribute to circular, low-carbon energy systems. Parallel improvements in resource efficiency through optimized water use, heat recovery systems, and advanced process automation further support the transition toward circular operations.

Environmental and Economic Implications

Research indicates that circular economy interventions can reduce greenhouse gas emissions, improve resource productivity, and strengthen long-term ecological resilience. Economically, circular practices may lower operational costs, reduce waste management expenses, and foster innovation-driven competitiveness. However, their implementation is not without challenges. High initial investment costs, technological limitations, regulatory barriers, and the need for cross-sector collaboration remain significant constraints. Moreover, behavioural change among consumers and supply-chain actors is essential for ensuring the successful adoption of circular models.

Net zero food system

A net-zero food system minimizes the greenhouse gas (GHG) emissions from all the processes involved such as food production, distribution, and consumption and any unavoidable emissions are balanced by carbon sequestration to achieve no net emissions. Net zero food system can thus be defined as a system that has achieved net zero balance of GHG emissions, which means any emissions, are balanced by an equivalent amount being removed from the atmosphere. This balance is achieved through regenerative agriculture, forest restoration etc. Key actions to achieve net-zero food system include:

- Shifting to more sustainable diets
- Reducing food loss and waste
- Using data to improve measurements

- Reporting and verification across entire food value chain



Figure 3. Diagrammatic representation of Net zero (Source: PwC website- <https://www.pwc.co.nz/industry-expertise/food-supply-and-integrity/sustainability-and-net-zero-transformation-in-the-food-system.html>)

Net zero food processing system aims to drastically reduce or eliminate GHG emissions across the entire food processing value chain with emissions offset by natural carbon removal and the key strategies include:

- Shifting to renewable energy
Move from fossil fuels to renewable energy sources like solar, wind power etc.
- Improving energy efficiency
- Reducing waste
Implement waste reduction & recycling programs to minimize food waste and packaging waste
- Optimizing water use
Implement water saving technologies and practices to save water
- Integrating digital and circular economy practices

- Process optimization
Optimize food processing operations to reduce energy consumption, water usage and waste generation
- Supply chain engagement
Engage with suppliers and stakeholders to promote sustainable practices through the supply chain
- Carbon offset
Invest in carbon offset projects to compensate for unavoidable emissions

This transformation requires a holistic approach involving companies, supplies, farmers, consumers and governments to drive systematic change. Some specific technologies and practices that can help achieve net zero in food processing are given below:

- Anaerobic digestion: convert food waste to fertilizer or biogas
- Solar drying: Use solar energy to dry food products, reducing energy consumption and preserving nutrients
- High pressure processing: use high pressure to preserve food, reducing energy consumption and preserving nutrients
- Smart packaging: Develop biodegradable or compostable packaging solutions to reduce plastic usage

Conclusion

The food processing sector plays a critical role in global food systems, linking primary production with consumer markets. However, it also contributes substantially to resource depletion, greenhouse gas emissions, and waste generation. As environmental concerns intensify, the concept of the circular economy and net zero has emerged as two promising approaches for transforming the sector's resource use, emissions and sustainability performance. A circular approach seeks to replace the previous linear model characterized by extraction, production, consumption, and disposal with strategies that retain resources within closed loops for as long as possible.

The circular economy provides a comprehensive framework for enhancing sustainability in the food processing sector. By emphasizing waste valorisation, material circularity, and resource-efficient technologies, circular economy strategies offer substantial environmental, economic, and social benefits. As global food systems face mounting pressures, circular models

represent a critical pathway toward more resilient and sustainable food production and consumption.

Achieving net-zero is a transformative approach in order to achieve long-term food security for an escalating population along with minimizing environmental degradation. Reaching net zero is necessary to stop further global warming. It requires deep cuts in emissions, for example by shifting from fossil fuels to sustainable energy, such as solar energy, wind energy etc. and improving energy efficiency and preventing deforestation. A small remaining fraction of emissions can then be offset using carbon dioxide removal. The adoption of circular economy practices and net-zero strategies can reshape the food processing industry, leading to more sustainable and responsible production.

References

- Alzaabi, S.A., Chia, W.Y. & Show, P.L. Exploring the potential of circular economy in the food sector. *Syst Microbiol and Biomanuf* **4**, 620–630 (2024). <https://doi.org/10.1007/s43393-023-00218-8>
- M.Drljača (2015) Tranzicija linearne u kružnu ekonomiju (Koncept učinkovitog upravljanja otpadom). III. International Conference, Proceedings Book Quality System Condition for Successful Business and Competitiveness, Association for Quality and Standardization of Serbia, Vrnjačka Banja, p.35-44.
- Mohammad Fazle Rabbi, Mohammad Bin Amin, Circular economy and sustainable practices in the food industry: A comprehensive bibliometric analysis, *Cleaner and Responsible Consumption*, Volume 14, 2024, 100206, ISSN 2666-7843, <https://doi.org/10.1016/j.clrc.2024.100206>.
- Mohan S V, Mohanakrishna G, Velvizhi G, Babu V L and Sarma P N 2010 J. Biochem. Eng. 51 pp 32–39
- PwC New Zealand website-<https://www.pwc.co.nz/industry-expertise/food-supply-and-integrity/sustainability-and-net-zero-transformation-in-the-food-system.html>
- UNEP statistics, 2024, <https://www.unep.org/resources/publication/food-waste-index-report-2024>
- Z.Zavargo, A.Jokić (2010) Koncept nulte emisije (Zero Emissions Concept), *Journal of Engineering&Processing Management*, 2(2), 79-89.

GREEN HOUSE GAS EMISSION IN AGRICULTURE AND ITS MITIGATION

Article ID: AG-VO5-I12-110

Suganthi R*, Poornima R and Priyadharshini S

Ph.D Scholar, Department of Environmental Sciences, Tamil Nadu Agricultural University,
Coimbatore, Tamil Nadu, India – 641 003

*Corresponding Author Email ID: suganthi.tamilselvi@gmail.com

Introduction

Agriculture, a crucial element of global security, is strongly influenced by climate change mainly due to human interventions. Agricultural practices that significantly contribute to global warming are raising livestock, rice cultivation, and using synthetic fertilizers which account for about 13% of the world's anthropogenic greenhouse gas emissions. This problem gets exacerbated by emissions of carbon dioxide (CO₂), nitrous oxide (N₂O), and methane (CH₄), with N₂O as of particular concern because of its high potential for global warming. Overall, agricultural activities—both crop and livestock production—play a key role in increasing atmospheric GHG levels, highlighting the need for sustainable practices to reduce emissions while meeting growing food demands. Soil is the key contributor and recipient of green house gases in terrestrial ecosystem. Several agricultural practises were modified to reduce the emission from the soil. According to IPCC sixth assessment report 2022, significant reductions in greenhouse gas emissions might result from switching to diets that include a greater proportion of plant protein, a moderate amount of foods derived from animals, and less saturated fat. In addition to improving health and lowering mortality from non-communicable illnesses linked to nutrition, advantages would also include decreased land occupancy and nutrient losses to the environment.

Driving factors of GHG emission from agricultural soil

Agriculture contributes to three major greenhouse gases—**carbon dioxide (CO₂)**, **methane (CH₄)**, and **nitrous oxide (N₂O)**—each with different sources and warming potentials.

1. Methane (CH₄) Emissions

Methane is the dominant GHG from agriculture. It has a warming potential ~28 times greater than CO₂ over 100 years. The Major sources are a) Enteric Fermentation (Ruminant digestion) - Cattle, buffalo, sheep, and goats release methane during digestion; Responsible for ~40% of global agricultural emissions b) Rice Paddy Cultivation - Flooded rice fields create anaerobic conditions → methane-producing bacteria thrive; Major contributor in countries like India, China, Bangladesh c) Manure Management - Storage of livestock manure under anaerobic conditions (slurry pits, lagoons) releases methane.

2. Nitrous Oxide (N₂O) Emissions

N₂O has a warming potential ~265 times greater than CO₂. The Major sources are a) Synthetic Fertilizers - Excess nitrogen fertilizers convert into N₂O through soil microbial processes (nitrification/denitrification) b) Organic Fertilizers - Manure and compost generate N₂O when decomposed in soils c) Crop Residue Burning - Releases N₂O along with CO₂ and particulate matter d) Nitrogen-fixing Crops - Legumes increase N availability, leading to some N₂O production.

3. Carbon Dioxide (CO₂) Emissions

Although smaller compared to CH₄ and N₂O, agriculture emits substantial CO₂ through land use and energy consumption. The Major sources are a) Deforestation for Agriculture - Clearing forests for cropland or pastures releases large carbon stocks; One of the largest indirect sources of agricultural CO₂ b) Soil Carbon Loss - Tillage and monocropping degrade soil organic matter, releasing CO₂ c) Machinery & On-Farm Energy Use - Tractors, irrigation pumps, food processing equipment consume fossil fuels d) Fertilizer Production - Energy-intensive process, especially nitrogen fertilizers.

4. Indirect Emissions

Agriculture also drives emissions outside farms: a) Supply Chain (transport, packaging, cold storage); b) Land-use change (forest to farmland); c) Agrochemical manufacturing (fertilizers, pesticides). These often double the emissions attributed to agriculture.

Microorganisms, root respiration, chemical oxidation processes, and soil respiration all release greenhouse gases into the atmosphere. GHG emissions are caused by an assortment of factors. Soil type and local climate are examples of proximal variables that affect soil emissions in the near vicinity and fall under the first category. Secondary drivers, such as temperature and

humidity, that affect soil emissions on larger scales make up the second group. When calculating the GWP of agricultural soil, several factors are crucial. Land use/land cover change, nutrient availability, temperature, humidity, soil hydrogen potential (pH), fertilizers, and organic additions are the main causes of greenhouse gas emission from agricultural soils.

Mitigation Strategies

Mitigating greenhouse gas emissions from agriculture involves improving both crop and livestock management. Key strategies include

Methane reduction

- Improved cattle feed & digestion inhibitors
- Enhanced manure management (composting and biogas/anaerobic digestion)
- Alternate wetting and drying (AWD) in rice cultivation
- Efficient irrigation technologies (Drip/sprinkler)

Nitrous oxide reduction

- Precision fertilizer application
- Use of slow release fertilizer nitrification inhibitors
- Organic soil management

Carbon dioxide reduction

- Agroforestry
- Conservation Agriculture (minimum tillage, residue retention, crop rotation)
- Soil carbon sequestration
- Renewable energy on farms

Smart Farming

Agricultural production has unquestionably increased with the advent of automated technologies, advanced data analytics, and IoT-based environmental monitoring. Nevertheless, a proportionate decrease in GHG emissions has not always followed from this technical breakthrough. A viable solution to the agriculture sector's substantial contribution to greenhouse gas (GHG) emissions is smart farming. However, there is still disagreement over how well modern smart farming techniques reduce greenhouse gas emissions. When paired with the capabilities of the recently released 6G wireless technology, the Internet of Things (IoT) in agriculture is a potent instrument for controlling greenhouse gas emissions. Fundamentally, IoT and 6G technologies make advantage of ultra-fast wireless networks and networked devices to

provide smooth data interchange and intelligent decision-making. Artificial intelligence (AI) and large-scale edge computing will function synergistically to analyze sensor data in real time, enabling targeted pest control, precise irrigation, and optimal fertilizer use. Because quantum sensing can assess soil moisture, nutrient levels, and plant health with extreme precision, it has the potential to completely transform the agricultural industry. This degree of precision will minimize needless waste and allow for focused interventions. Additionally, quantum communication will guarantee the safe transfer of this extremely private information, shielding it from tampering and eavesdropping. In order to facilitate effective decision-making, four-dimensional communication will provide wide coverage and extremely quick transfer of sensitive data, such as real-time crop health information from remote sensors.

Conclusion

It is plausible to maneuver the complex interactions between societal demands, environmental responsibility, and the agricultural industry's economic viability in the face of a changing climate by pursuing sustainable practices that balance ecological goals with the pragmatic requirements of agriculture. Globally, thorough evaluations incorporate location-specific data, regional data collection, reporting, and satellite data via relevant models. When paired with tillage, irrigation, and drainage techniques, efficient manure management may greatly lower soil greenhouse gas emissions while increasing crop yields. In addition to lowering emissions from agricultural soils, bio-resources and nutrient management improve environmental sustainability. Developing effective plans requires assessing the GWP and utilizing a variety of mitigating methods. These include supervising cropping systems, bio-resources, fertilizers, manure, tillage, irrigation, and drainage. Governments must give climate-smart agriculture technology top priority in order to close this gap, with a focus on improving the agricultural sector's input usage efficiency. A more successful and significant approach to GHG mitigation may be achieved by resolving these challenges and encouraging the use of ecologically friendly farming methods.

References

- Pathak, H. (2015, December). Greenhouse gas emission from Indian agriculture: trends, drivers and mitigation strategies. In *Proc Indian Natl Sci Acad* (Vol. 81, No. 5, pp. 1133-1149).
- Basheer, S., Wang, X., Farooque, A. A., Nawaz, R. A., Pang, T., & Neokye, E. O. (2024). A review of greenhouse gas emissions from agricultural soil. *Sustainability*, 16(11), 4789.



- Xing, Y., & Wang, X. (2024). Impact of agricultural activities on climate change: A review of greenhouse gas emission patterns in field crop systems. *Plants*, 13(16), 2285.
- Polymeni, S., Skoutas, D. N., Sarigiannidis, P., Kormentzas, G., & Skianis, C. (2024). Smart agriculture and greenhouse gas emission mitigation: A 6G-IoT perspective. *Electronics*, 13(8), 1480.

WORLD SOIL DAY THEMES AND ITS IMPORTANCE

Article ID: AG-VO5-I12-111**Dr. C. Sivaranjani¹ and Dr. R.Vinoth²**¹Senior Research Fellow, Dept. Soil Science and Agrl. Chemistry²Teaching Assistant (PBG), Department of Genetics and Plant Breeding

Institute of Agriculture, TNAU, Kumulur, Trichy, Tamil Nadu, India

*Corresponding Author Email ID: sranjani0492@gmail.com

Introduction

Soil is the basis for food, feed, fuel and fibre production and for services to ecosystems and human well-being. It is the reservoir for at least a quarter of global biodiversity, and therefore requires the same attention as above-ground biodiversity. Soils play a key role in the supply of clean water and resilience to floods and droughts. The largest store of terrestrial carbon is in the soil so that its preservation may contribute to climate change adaptation and mitigation. The maintenance or enhancement of global soil resources is essential if humanity's need for food, water, and energy security is to be met. World Soil Day is held annually on 5 December as a means to focus attention on the importance of healthy soil and to advocate for the sustainable management of soil resources, and has been facilitated by the Food and Agriculture Organization of the United Nations (FAO) since 2014.

World Soil Day (WSD) is held annually on 5 December as a means to focus attention on the importance of healthy soil and to advocate for the sustainable management of soil resources. An international day to celebrate soil was recommended by the International Union of Soil Sciences (IUSS) in 2002. Under the leadership of the Kingdom of Thailand and within the framework of the Global Soil Partnership, FAO has supported the formal establishment of WSD as a global awareness raising platform. The FAO Conference unanimously endorsed World Soil Day in June 2013 and requested its official adoption at the 68th UN General Assembly. In

December 2013, the UN General Assembly responded by designating 5 December 2014 as the first official World Soil Day.



In the face of the triple planetary crisis of climate change, biodiversity loss, and pollution, our soils are being degraded and polluted, putting excessive pressure on this precious resource and the food systems that depend on it. Food is at the center of human lives, and so are the soils that support food systems. However, unsustainable food production and consumption practices have led to environmental degradation, including soil degradation, and exacerbated climate change. In return, food systems suffer from climate change, biodiversity loss and pollution.

Land and soil degradation pose a major threat to global food security and to the achievement of the Sustainable Development Goals (SDGs) – compromising the well-being of at least 3.2 billion people around the world. Loss of soil biodiversity, soil erosion, pollution and salinization are all critical issues that need to be addressed to ensure food security, livelihoods, and health for all.

As the leading organization on the issue, FAO provides numerous resources to better understand the role of soil and food systems for a sustainable future, as well as challenges and ways forward. In light of recent international negotiations and debates on plastic pollution, the role of plastics in agriculture and the subsequent soil pollution has also been under focus.

Food is at the center of human lives. Not only is food is condition for our existence, it is also at the basis of our cultural norms and social lives. Food production is provides the livelihood for the [883 million people](#) employed in the agriculture sector. As nature provides the foundation for plants to grow and animals to live, food is intrinsically connected to the environment. However, unsustainable food production and consumption practices have led to environmental

degradation and exacerbated climate change. In return, food systems suffer from climate change, biodiversity loss and pollution.

World Soil Day celebration

World Soil Day, observed annually on 5 December, underscores the critical importance of soil as a vital natural resource and promotes the sustainable management of soil ecosystems. The observance aims to raise global awareness about key challenges such as soil degradation, erosion, nutrient imbalance, contamination and the urgent need to safeguard soil biodiversity. Each year, WSD is commemorated with a specific global theme addressing pressing soil-related concerns, including drought, salinity, soil health, sustainable fertilization and organic matter restoration.

The day serves as a powerful reminder that soil is a finite and fragile resource. Its conservation is fundamental to ensuring food security, enhancing climate resilience, protecting the environment and securing the well-being of future generations. By advocating science-based soil health initiatives, World Soil Day reinforces global commitment toward sustainable agri-food systems and the protection of one of Earth's most valuable natural assets.

In alignment with this global observance, ICAR Institutes across India celebrated World Soil Day through awareness programmes, scientific talks, demonstrations and outreach activities aimed at promoting soil health and sustainable agricultural practices among farmers, students and stakeholders.

Every year especially theme was made and the world soil day was give importance

World Soil Day 2014 - Soils, foundation for family farming

Family Farming Focus: The theme emphasized how soil health directly supports small-scale farmers who produce much of the world's food. **Goal:** To raise awareness about sustainable soil management and its role in food security, biodiversity, and environmental resilience

World Soil Day 2015 - Soils, a solid ground for life

- ✓ Highlighting soil as the basis for food, water, biodiversity, and climate regulation, connecting it directly to human well-being.
- ✓ Encouraging efforts to reverse soil neglect and promote soil preservation through initiatives like India's Soil Health Card Scheme.

World Soil Day 2016 - Soils and pulses, a symbiosis for life

- ✓ Emphasized the mutually beneficial link between soil and pulses.

- ✓ Showcased pulses as nutritious food sources.
- ✓ Focused on how pulses enhance soil fertility and support sustainable farming practices.
- ✓ Linked to the UN's Sustainable Development Goals (SDGs) for ending hunger, adapting to climate change, and preserving biodiversity

World Soil Day 2017 - **Caring for the Planet starts from the Ground**

- ✓ Highlighting soil as the base for agriculture and healthy ecosystems.
- ✓ Drawing attention to soil organic carbon's role in combating climate change.
- ✓ Addressing concerns about plant protection products (pesticides) and their effects on soil

World Soil Day 2018 - **Be the solution to soil pollution**

Raising awareness about how human activities **cause** soil contamination and urging everyone to take action, like reducing waste and using fewer chemicals, to protect this vital resource for food security and ecosystem health.

- ✓ Soil pollution from chemicals, waste, and industrial/agricultural runoff threatens food, water, and health.
- ✓ Encouraged simple actions like using reusable bags, reducing packaging, and adopting organic practices to combat pollution.
- ✓ To secure healthy soil for future generations and mitigate climate change impacts

World soil day 2019 - **Stop Soil Erosion, save our Future**

Highlighting the critical need to address soil degradation and promote sustainable soil management for human well-being and healthy ecosystems, as soil erosion poses a significant threat to life on Earth. The campaign encouraged global action to improve soil health and protect it from loss.

- ✓ The theme pointed to the increasing rate of soil loss, with the UN noting that an area of soil equivalent to a soccer field is lost every five seconds.
- ✓ It emphasized soil as the foundation for food, habitat, and life, urging governments, organizations, and individuals to act.
- ✓ It served as a global call to proactively improve soil health and prevent erosion.

World soil day 2020 - **Keep soil alive, Protect soil biodiversity**

Focusing on the importance of tiny organisms in soil for healthy ecosystems, carbon storage, and food production, urging action against biodiversity loss beneath our feet. Celebrated

annually on December 5th, the campaign encouraged understanding how microbes, fungi, worms, and insects sustain life and fight climate change.

Emphasized the "alive" nature of soil and the need to protect its diverse life forms, from bacteria to earthworms.

- ✓ Soil biodiversity is crucial for nutrient cycling, water purification, carbon storage, and supporting plant growth, making it vital for food security and climate resilience.
- ✓ To raise awareness and promote sustainable soil management to combat the threats of soil biodiversity loss.

World soil day 2021 - **Halt Soil Salinity, Boost Soil Productivity**

This campaign focused on raising awareness about the dangers of soil salinization (salt accumulation) and encouraging sustainable practices to prevent soil degradation and improve agricultural output, highlighting soil as a vital resource for food and life.

- ✓ To fight against the growing threat of soil salinization and enhance the productivity of agricultural lands.
- ✓ Salinization degrades soil, making it less fertile; halting this process is crucial for food security and healthy ecosystems.
- ✓ Promoted soil testing, balanced fertilizer use, and water management to protect soil health.

World soil day 2022 - **Soils: Where food begins**

Focusing on the crucial role of healthy soil in producing our food, ensuring food security, and supporting human well-being and ecosystems. The initiative aimed to raise awareness about soil degradation and encourage sustainable management practices.

- ✓ Soil produces 95% of our food, making it fundamental for survival.
- ✓ Healthy soil supports biodiversity, filters water, and maintains stable ecosystems.
- ✓ The theme called for actions like covering soil, adding compost, and avoiding harmful burning to improve soil health.

World soil day 2023 - **Soil and Water: A Source of Life**

Highlighting the vital, symbiotic connection between soil and water for ecosystems, food production (over 95% of food comes from them!), and overall planetary health, urging action against threats like degradation, erosion, and pollution.

- ✓ Emphasized that healthy soil and water are essential for nutrient absorption by plants and the functioning of all terrestrial life.
- ✓ Underlined that these resources are the foundation of agriculture and our food supply.
- ✓ Called attention to soil degradation, erosion, and pollution, advocating for sustainable management practices

World soil day 2024 - **Caring for Soil—Measure, Monitor, and Manage**

Highlighting the critical need for accurate soil data and information to guide sustainable management practices for food security, climate change, and healthy ecosystems. This theme emphasized understanding soil characteristics to make informed decisions for better soil health and protection.

- ✓ Using reliable data to manage soils effectively.
- ✓ Supports food production, combats climate change, and ensures clean water and air.
- ✓ Marked the 10th anniversary of World Soil Day

World soil day 2025 - **Healthy Soils for Healthy Cities**

"Healthy Soils for Healthy Cities", invites everyone – from policymakers to citizens – to build greener, more resilient, and healthier cities.

Conclusion

The theme promotes the fundamental role of urban soil. Beneath asphalt, buildings, and streets lies soil that, if permeable and vegetated, helps absorb rainwater, regulate temperature, store carbon, and improve air quality. However, when soil is sealed with cement, it loses these functions, making cities more vulnerable to flooding, overheating, and pollution. The theme for 2025, “**Healthy soils for healthy cities**”, focuses on the role of soils in cities and the challenges posed by soil sealing and urbanization. Urban soils provide essential ecosystem services: they support food production, filter water, store carbon, regulate temperatures, and sustain biodiversity. World Soil Day 2025 is a call to action. It invites policymakers, scientists, city leaders, civil society, and citizens everywhere to reimagine urban spaces through their soils, ensuring that people and nature can thrive together in healthy green cities.

INDIA'S BIG STEP TOWARD TRANSPARENT SEAFOOD

Article ID: AG-VO5-I12-112**Dave Chandani Prakashbhai***

ICAR-Central Institute of Fisheries Education, Versova, Mumbai, India

*Corresponding Author Email ID: davechandani2000@gmail.com

Abstract

Seafood traceability has emerged as a critical component of contemporary fisheries governance, linking food safety, sustainability, and market access in an increasingly regulated global trade environment. India's recent launch of a National Framework on Seafood Traceability represents an important institutional response to these evolving demands. This article examines the scope and significance of the framework within India's highly diverse fisheries and aquaculture sector, characterised by small-scale producers, inland fisheries dominance, and complex supply chains. Drawing comparative insights from neighbouring seafood-producing countries such as Indonesia, Vietnam, Thailand, and China, the article situates India's initiative within a broader regional transition toward digital traceability systems. While acknowledging implementation challenges related to scale, capacity, and coordination, the discussion highlights the framework's potential to enhance transparency, strengthen export credibility, and support inclusive participation of fishers and farmers. The article argues that, if implemented with a user-centric and phased approach, India's traceability framework can serve as a catalyst for sustainable and trusted seafood value chains.

Key Words: Seafood traceability; Small-scale fisheries; Digital governance; Sustainable seafood trade; India

Introduction

Change has begun in India's seafood sector. With the launch of a national seafood traceability framework, the Government of India has set in motion a system that seeks to follow fish and shrimp from the pond or vessel where they originate to the markets where they are

finally consumed. For a country that is among the world's largest producers and exporters of fish and aquaculture products, this marks a significant shift—from fragmented documentation to an integrated vision of transparency, credibility, and sustainability.

Seafood traceability, once viewed largely as a compliance requirement imposed by importing countries, is increasingly being recognised as a strategic tool. It connects food safety with livelihoods, sustainability with market access, and governance with consumer trust. India's framework arrives at a moment when global seafood trade is being reshaped by concerns over illegal fishing, environmental degradation, and ethical sourcing. Against this backdrop, India's move is not just timely—it is forward-looking.

What Is Seafood Traceability and Why It Matters

At its core, seafood traceability refers to the ability to track and verify information about seafood products at every stage of the supply chain—from harvest or culture to processing, distribution, and final sale. This includes details on origin, species, production method, handling, and movement across intermediaries. When implemented effectively, traceability systems allow regulators to ensure food safety, buyers to verify legality and sustainability, and consumers to make informed choices.

Globally, traceability has become central to fisheries governance. The European Union's catch certification scheme, the United States' Seafood Import Monitoring Program, and similar measures elsewhere have raised the bar for exporting countries. Beyond compliance, traceability is increasingly linked to sustainability certifications, eco-labelling, and even emerging discussions on carbon-conscious seafood. For exporting nations, it is no longer a peripheral requirement but a core element of competitiveness.

India's National Framework on Seafood Traceability reflects this broader understanding. Rather than treating traceability as a narrow export obligation, the framework positions it as a system-wide reform aimed at improving transparency, efficiency, and trust across the fisheries and aquaculture value chain.

India's National Framework: Vision and Scope

India's fisheries and aquaculture sector is vast and diverse. It encompasses marine capture fisheries spread across a long coastline, inland capture fisheries in rivers and reservoirs, and a rapidly growing aquaculture sector dominated by shrimp and freshwater fish. Millions of

small-scale fishers and farmers are part of this system, supplying both domestic and international markets.

The national traceability framework seeks to bring coherence to this complexity. It outlines a structured approach for digitally recording and sharing information across key stages of production and trade. By promoting standardised data formats and interoperable systems, the framework aims to reduce duplication, improve data reliability, and facilitate end-to-end traceability.

Importantly, the framework acknowledges India's ground realities. It recognises that traceability systems must be scalable, cost-effective, and user-friendly to work in a sector dominated by smallholders. The emphasis, therefore, is not only on technological solutions but also on institutional coordination, capacity building, and phased implementation.

India's Unique Challenge: Scale and Diversity

One of India's defining characteristics is scale. The country produces seafood across thousands of landing centres, ponds, and farms, involving a wide range of species and production systems. Inland fisheries alone contribute a substantial share of total fish production, often through dispersed and informal channels. This diversity poses undeniable challenges for traceability.

Yet, scale can also be a strength. Designing traceability systems that work for India requires innovation—simple digital tools, mobile-based data entry, multilingual interfaces, and integration with existing institutional structures such as cooperatives, fish farmer producer organisations, and extension networks. Solutions developed for India's context have the potential to become models for other large, smallholder-dominated food systems.

Rather than viewing complexity as a barrier, the national framework treats it as a design driver. By focusing on inclusivity and practicality, the framework opens the door for a traceability system that is not only robust but also socially embedded.

Learning from Neighbours: A Regional Perspective

India is not alone in strengthening seafood traceability. Across Southeast and East Asia, major seafood-producing nations have been investing in digital systems to enhance transparency and meet international expectations. A brief look at neighbouring countries offers useful insights. Indonesia has emerged as a regional leader with government-led digital traceability initiatives aimed at tracking seafood from vessels to markets. Its national systems demonstrate the value of

strong public-sector coordination and clear mandates. Vietnam, a major seafood exporter, has focused on electronic traceability in ports and export-oriented value chains, particularly in shrimp, aligning closely with international market requirements. Thailand's traceability reforms, shaped by earlier international scrutiny, highlight how regulatory reform and digital monitoring can restore credibility and improve governance. China, with its vast domestic market and complex supply chains, illustrates both the possibilities and challenges of implementing traceability at scale.

India's approach draws lessons from these experiences while charting its own path. Unlike some neighbours that focus primarily on export chains, India's framework explicitly recognises the importance of integrating inland fisheries and small-scale producers. This inclusive vision sets it apart and reflects an ambition to build a system suited to India's social and economic realities.

What Traceability Means for Fishers and Farmers

For fishers and aquaculture farmers, traceability can appear abstract or burdensome if framed purely as a regulatory requirement. However, when designed thoughtfully, it can offer tangible benefits. Digital records can improve access to markets, reduce disputes over quality and origin, and strengthen bargaining power by making production practices visible.

In the long run, traceability can support differentiation and value addition. Responsible practices, once documented and verified, can be linked to certification schemes and premium markets. For small-scale producers, this creates the possibility of being recognised not just as suppliers of raw material, but as participants in transparent and sustainable value chains.

The success of India's framework will depend on whether these benefits are clearly communicated and realised on the ground. Training, handholding, and trust-building will be as important as technology.

Implications for Exporters, Regulators, and Consumers

For exporters, a national traceability system promises greater efficiency and reduced compliance risk. Harmonised data systems can simplify reporting, speed up clearances, and enhance confidence among international buyers. For regulators, traceability offers a powerful tool for monitoring food safety, legality, and sustainability without relying solely on inspections. Consumers, both domestic and international, stand to gain from greater transparency. As awareness of food safety and sustainability grows, traceability helps bridge the gap between

producers and consumers, fostering trust in seafood products. In an era of misinformation and complex global supply chains, credible traceability systems are becoming essential to maintaining consumer confidence.

Making It Work: Enablers for Success in India

While the framework sets a strong direction, implementation will be key. Several enabling factors can support success:

- Phased implementation that allows learning and adaptation
- User-centric design focused on simplicity and affordability
- Capacity building through cooperatives, producer organisations, and extension services
- Integration with existing databases and certification systems
- Public–private collaboration to leverage industry expertise and innovation

By prioritising usability and relevance, India can ensure that traceability becomes an everyday practice rather than an administrative burden.

Conclusion: An Opportunity to Lead Inclusively

Seafood traceability is often framed as a response to external pressure from importing countries. India's national framework offers an opportunity to move beyond that narrative. By embedding traceability within a broader vision of sustainable growth, livelihood security, and global credibility, India is positioning itself for the future of seafood trade.

The journey will not be without challenges. Yet, if implemented with sensitivity to local contexts and a commitment to inclusion, India's traceability framework has the potential to become more than a compliance tool. It can be an instrument of trust—connecting ponds and ports to plates and people across the world and reinforcing India's role as a responsible and reliable seafood producer.

References

- Food and Agriculture Organization of the United Nations (FAO). *Voluntary Guidelines on Catch Documentation Schemes*. FAO, Rome, 2017, 1–92.
- FAO. *The State of World Fisheries and Aquaculture*. FAO, Rome, 2022, 1–266.
- OECD. *Rebuilding Fisheries: The Way Forward*. OECD Publishing, Paris, 2018, 1–190.
- Ponte S., Sturgeon T. J. (2014). Explaining governance in global value chains. In Gereffi G., Lee J. (Eds.), *Global Value Chains and Development* (pp. 191–215). Cambridge: Cambridge University Press.

Department of Fisheries, Government of India. *National Framework on Traceability in Fisheries and Aquaculture*. Ministry of Fisheries, Animal Husbandry and Dairying, New Delhi, 2025, 1–38.

European Commission. *EU Catch Certification Scheme to Combat IUU Fishing*. Publications Office of the European Union, Luxembourg, 2010, 1–52.

National Oceanic and Atmospheric Administration (NOAA). *Seafood Import Monitoring Program Final Rule*. NOAA Fisheries, Silver Spring, 2016, 1–84.

Global Dialogue on Seafood Traceability (GDST). *GDST Standard 1.0*: GDST, Washington DC, 2022, 1–64.

ASEAN. *Guidelines for Traceability Systems for Aquaculture Products*. ASEAN Secretariat, Jakarta, 2021, 1–45.

National Framework on Traceability in Fisheries and Aquaculture. <https://pib.gov.in>. Accessed on 15 November, 2025.

Global Dialogue on Seafood Traceability. <https://www.gdst.org>. Accessed on 10 November, 2025.

FAO Fisheries and Aquaculture Traceability Resources. <https://www.fao.org/fisheries>. Accessed on 12 November, 2025.



Volume: 05 Issue No: 12

WOMEN'S LEADERSHIP IN CLIMATE CHANGE ADAPTATION AND MITIGATION EFFORTS

*"With women at the helm, the earth finds balance"***Article ID: AG-V05-I12-113****Chetna Pathak^{1*}, Abhijeet Kuderiya² and Dr. Seema Naberia³**^{1&2} PhD Scholar, Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur 482004 (M.P.) India.³ Assistant Professor, Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur 482004 (M.P.) India

*Corresponding Author Email ID: csapathak@gmail.com

Abstract

Climate change is a global crisis that affects populations unevenly, with women experiencing disproportionate impacts due to socio-economic inequalities, limited access to resources, and traditional gender roles. At the same time, women play a critical role in climate change adaptation and mitigation through leadership, local knowledge, and community engagement. Gendered dimensions of climate change are evident across rural, agricultural and post-disaster contexts, where women contribute significantly to adaptation and mitigation efforts. Their roles in natural resource management, disaster risk reduction, sustainable consumption, renewable energy initiatives and climate advocacy demonstrate their capacity as agents of change. Particular attention is drawn to the contributions of indigenous women and women-led recovery initiatives following major climate-induced disasters. Strengthening women's leadership and ensuring their active participation in climate action are essential for building resilient communities and achieving sustainable and equitable climate outcomes.

Keywords: Women leadership, Climate change, Adaptation, Mitigation, Gendered impacts, Disaster risk reduction, Sustainable development, Renewable energy

Introduction

Climate change is an undeniable global crisis that necessitates immediate and sustained action. As we grapple with its effects, it is increasingly evident that women, particularly those in leadership roles, are essential in driving effective climate change adaptation and mitigation

efforts. Their unique perspectives and capacities contribute significantly to building resilient communities and fostering sustainable development.

It is often assumed that all members of a population experience the impact of disasters in the same way. However, natural disasters are not neutral; they affect women, men, girls, and boys differently due to gender inequalities caused by socio-economic conditions, cultural beliefs, and traditional practices, which have repeatedly put females at a disadvantage.

The Gendered Impact of Climate Change

Climate change impacts everyone, but not equally. Women, especially in developing countries, are disproportionately affected due to their social roles, limited access to resources, and economic dependency. They often bear the brunt of climate-related disasters, such as droughts, floods, and hurricanes, which can exacerbate existing inequalities and vulnerabilities. Despite these challenges, women are not just passive victims but active agents of change. Their involvement in climate action can lead to more inclusive and effective strategies for adaptation and mitigation.

The climate crisis does not affect everyone equally. Women and girls face disproportionate impacts from climate change largely because they make up the majority of the world's poor, who are highly dependent on local natural resources for their livelihoods. When extreme weather disasters strike, women and children are 14 times more likely to die than men, mostly due to limited access to information, limited mobility, decision-making, and resources. An estimated four out of five people displaced by the impacts of climate change are women and girls. Acute disasters can also disrupt essential services, including sexual and reproductive health care, compounding the negative impacts for women and girls (United Nations).

Women's Roles in Climate Adaptation

Women's leadership in climate adaptation is particularly crucial in rural and agricultural communities, where they are often the primary managers of natural resources. Their local knowledge and practices are invaluable for developing sustainable agricultural techniques, conserving water, and protecting biodiversity. For example, in many parts of Africa and Asia, women have been at the forefront of adopting climate-resilient farming practices such as agroforestry, crop diversification, and soil conservation. These practices not only enhance food security but also increase the resilience of ecosystems to climate impacts.

Moreover, women play a critical role in disaster risk reduction and community resilience. They are often the first responders during climate-induced disasters, providing essential care and support to affected communities. Women's involvement in early warning systems, emergency preparedness, and post-disaster recovery efforts can significantly improve the effectiveness of these measures. For instance, in Bangladesh, women-led community groups have successfully implemented flood-resilience programs that include building elevated homes, planting trees along riverbanks, and developing evacuation plans.



In wealthier societies, women drive 70–80 per cent of all consumer purchasing decisions, leading the transition to more sustainable lifestyles. Women are more likely to recycle, minimize waste, buy organic food and eco-labelled products, and save water and energy in the household. By leading behaviour change and influencing consumer attitudes, women can drive change across sectors.

Women are also increasingly contributing to the renewable energy sector, currently accounting for 40 per cent of employees in solar energy—a much higher share than in the oil and gas sector (22 per cent). It is time to invest in women as a strong force for change, leading the way to a more sustainable future.

Women's Contributions to Climate Mitigation

The process of differentiating the impacts of climate change on women, indigenous peoples, farmers, and others, as well as their contributions to mitigation and adaptation, is crucial when climate change policies are formulated and programmes are designed, implemented, and evaluated. Addressing climate change from this perspective helps surface issues of social justice, equality, and empowerment, which are sometimes ignored in climate change debates.

Indigenous women have strong potential to contribute to climate change mitigation and adaptation. Since they greatly depend on various ecosystems and the services derived from them,

they possess knowledge on how to sustain and manage these resources and how to adapt when changes occur. Many of them are traditional knowledge holders and practitioners of sustainable development. They are among the sectors of society with the smallest ecological footprints.

One notable example is the growing number of women-led initiatives in the renewable energy sector. Women entrepreneurs and community leaders are championing the use of solar, wind, and bioenergy in their communities. In India, for instance, the organization *Solar Sister* empowers women to become clean-energy entrepreneurs by providing them with training and resources to distribute solar lanterns, cookstoves, and other renewable energy products. This initiative not only reduces carbon emissions but also creates economic opportunities for women, contributing to their empowerment and financial independence.

Women's involvement and advocacy are also very important in influencing climate legislation and igniting political action. Women activists and leaders are frequently at the vanguard of climate movements, bringing attention to the pressing need for climate action and holding businesses and governments accountable. Significant legislative changes and the adoption of climate-friendly practices at the local, national, and global levels are the results of their efforts. For instance, millions of people have been inspired by Greta Thunberg's global climate strikes and Vandana Shiva's advocacy for sustainable agriculture.

While the post-disaster context presents a host of challenges for women, it is important to recognize that women are not just victims of disasters. Rather, substantial evidence demonstrates that women are powerful agents of change during and after disasters. In the aftermath of Hurricane Mitch, which devastated Honduras and Nicaragua in 1998, women organized disaster recovery efforts, including hauling cement and building temporary shelters and latrines, in addition to undertaking governance initiatives and working to restore livelihoods.

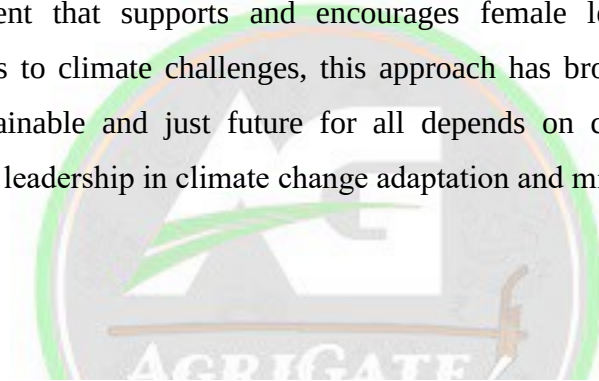


Women work at a SHORECO site in India. © Vandana Shiva. Photo Credit: The Hindu

After the 2015 earthquake in Nepal, women played a crucial role in rebuilding efforts, despite the disproportionate impact the disaster had on them. Some women were trained as masons to help repair and reconstruct houses, infrastructure, and cultural sites to be earthquake-proof. Women's groups also successfully advocated for the integration of gender equality and women's empowerment in disaster recovery and reconstruction efforts in the country. This resulted in the 15-point Kathmandu Declaration on Disaster Risk Management (DRM), endorsed by government authorities and development partners, which set out key demands for gender-responsive recovery and reconstruction.

Conclusion

The full potential of women to lead transformative climate action can be realized by creating an environment that supports and encourages female leadership. In addition to strengthening responses to climate challenges, this approach has broader social and economic benefits. A more sustainable and just future for all depends on continued support for and investment in women's leadership in climate change adaptation and mitigation initiatives.



INNOVATING INDIA'S AGRICULTURAL SUPPLY CHAIN: BLOCK CHAIN TECHNOLOGY AND SCHEMES AT WORK

Article ID: AG-VO5-I12-114**Teja Kumar D, A P SriVidhya and J Paul Mansingh***

VIT School of Agricultural Innovations and Advanced Learning (VAIAL),
Vellore Institute of Technology, Tamil Nadu, India.

*Corresponding Author Email ID: paul.mansingh@vit.ac.in

Introduction

India produces a lot of fresh produce, but a lot of it spoils before it reaches customers since there aren't enough facilities for refrigerated storage and shipping. Due to post harvest losses and decreased revenue, the farmers are forced to sell their products at reduced rates or risk having their items wasted. The efficient flow of agricultural products from producers to consumers is greatly aided by the agro supply chain. However, there are delays, inefficiencies, and a lack of transparency are common problems for traditional process in the supply chain of the agricultural industry. Technologies has thankfully created opportunities for creative solutions that have the potential to completely transform agro-supply chain operations by improving sustainability, efficiency and transparency. Fig.1 indicates the market value of supply chain management from 2023-2034 in USD Billions. As the current Market value is about 0.91-1.10 USD Billions and is expected to reach about 2.60 USD Billions in 2034.

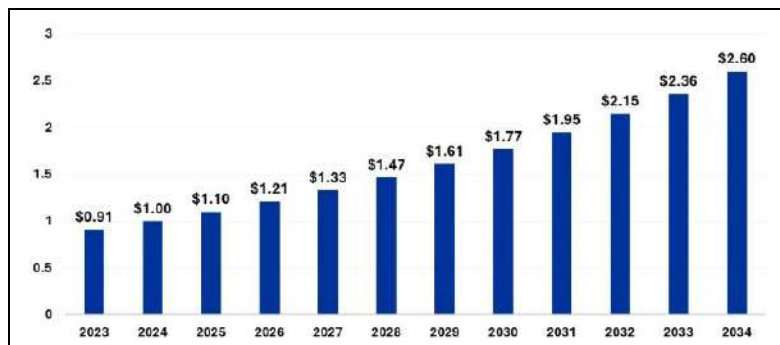


Fig 1. Agriculture Supply Chain Management Market Size 2023 to 2034 (USD Billion)

Source: precedence research (November, 2022)

Supply Chain Management

Supply chain generally focuses on the flow of goods and information between companies involved in sourcing raw materials, transforming them into finished products, and distributing them to end consumers. The supply chain for fresh agricultural products begins with farmers or planters who sell their produce to primary processors. The processors then prepare the produce before packaging and shipping it to wholesalers. Supply chains are driven by information and help businesses reduce costs, add value to their products, optimize resource utilization, minimize time to market, and satisfy consumers. The success of a supply chain is measured by how well operations across the chain align to create value for consumers while enhancing the profitability of each link. In other words, supply chain operations involve an interconnected process of delivering value to end consumers.

Top Agricultural Supply Chain Companies and Startups (2025):

In India, majority of the companies uses technologies for the management of supply chain technology which mainly focuses on the quality of the produce which are procured from the farmers, transparency of the produce that are being delivered to the end consumer and cost effectiveness for both the farmers and the consumers. The Top Agricultural supply chain companies and startups in India are included in the Table 1.

Table 1. Top Agricultural Supply Chain Companies and Startups (2025)

Company/Startup	Description
SfarmsINDIA	SfarmsIndia results makes mandatory for sellers to issue a digital contract against their lands. Eliminates middlemen who increases prices without proper reasons.
KhetiGaadi	It simplifies the purchase, sales, or rental of the farm equipment's for farmers and those who are associated with farming practices.
Crofarm	Crofarm is one of the most valued companies in the country for B2B2C space. This startup help's to reduce the food wastage and provides better food quality.
Farm2farm	It is an small startup and it addresses the gap where a group of customers is willing to spend higher amount for the better food

	quality.
Bombay Hemp Company (BOHECO)	It is one of the companies which is established to handle hemp supply chain in the country.
AgricxLab	It provides an AI enabled Software as a Service(SaaS) stack for businesses and entities that produce, store and transport agricultural commodities.
Fassal	It provides microclimatic forecasts, pest and disease predictions, and irrigation alters using its own exclusive technologies and deliver's the result's directly to the smartphones.
Cropin	It helps the farmers by providing the infrastructure needed to optimize their farming skills and start their businesses.

Source: Authors' Compilation (2025)

How are technological innovations transforming the supply chain in India?

Globally technological advancements have been changing a number of industries, including integrated supply chains. Indias businesses are no different. Businesses are implementing new tactics and tools to boost Productivity, cut experiences and enhance supply chain performances as a result pf technological advancement. The Government of India has been actively investing and promoting technological advancements in the supply chain industry. The Electronic Data Interchanged (EID) System, introduced by the ministry of commerce and industry in 2020, Simplifies the electronic exchange of documents pertaining to trade. The ultimate goal of this initiative is to increase supply chain efficiency by cutting down on paperwork, streamlining customs procedures, and expediting the clearance process

The Functions of Fresh Produce in the Agricultural Supply Chain

For in-store Companies like supermarkets and convenience store, the availability of fresh food is crucial. When selecting their principal retailers, consumers give priority to fruits and vegetables of superior quality. Concerns over the sustainability of agricultural products in the future have been raised by recent trends, nevertheless. India's need to reevaluate its approach has been brought to light by fluctuating rainfall patterns, rising food consumption, notable farming productivity gaps when compared to neighbouring nations, and the necessity of controlling food prices and import dependency to satisfy demands.

Significant Challenges in the Agri Supply Chain

Dealers in the agricultural supply chain face numerous obstacles. Inefficiencies in the supply chain are compounded by a lack of traceability, excessive storage costs, and various other issues.

1. Inadequate Packaging Techniques

A lot of commodities are shipped to markets or storage facilities without proper packaging, security or separations which can cause serious harm. For the purpose of continuing and negotiating, goods are frequently thrown to the ground. Before the products are put back onto trucks for additional transportation, some sorting and grading may take place on the spot. This procedure leads to further waste.

2. Security and Safety Concerns

Fresh produce logistics must comply with a number of food safety regulations, including those pertaining to warehouse, cleanliness, storage, and transportation, among them. For instance, transportation trucks need to be able to handle various cargo conditions and adhere to ISO requirements. Every step of the supply chain may experience negativity financial and legal repercussions if these regulations are broken.

3. Extravagant Conservation

A fresh food supply chain requires careful preservation as it needs to be stored at appropriate temperatures, well-packaged, and promptly handled.

4. Challenges Faced by Farmers

Indian Farmers face a number of issues, one of which is how to fairly price their goods.



Fig 2. Challenges faced by the Farmer

Source: Author's Compilation (2025)

Significant demand, a lack of awareness of high-value crops, a lack of exposure to high-productivity practices, a lack of market connections, ineffective supply networks that result in food waste, and a heavy reliance on rainfall all affect the soil and water. Capturing the whole value chain- from agriculture to the point where farmers may benefit is crucial to bringing about a revolution in agricultural revenue. Fig.2. Shows the challenges faced by the farmers

Benefits of Modern Technology

- In the age of digital transformation, technology has become an indispensable tool for modernizing agricultural supply chains. From farm to table, every stage of the agricultural supply chain can benefit from technological innovations that improve efficiency, traceability, and sustainability.
- Companies specializing in digital agriculture provide cutting-edge technology solutions to enhance agricultural productivity and efficiency.
- Request relation technology platforms connect agricultural products with potential consumers, improving supply chain effectiveness.

Block chain technology in Agriculture

Blockchain technology is still relatively new to the agricultural industry, but it's already making great strides. This is astounding growth, and for proponents of blockchain technology, it's extremely exciting. But what benefits does it bring to agriculture and the food supply? - When Combined with agriculture, block chain technology offers the following benefits:

- Improved food safety and quality control
- Efficiency and equity of farmer payments
- Traceability and transparency
- Environmental sustainability

Key Government Initiatives

The Government schemes and policies in INDIA impact the agricultural supply chain by both improving the infrastructure and market access through the initiatives like e-NAM and the Agriculture Infrastructure fund (AIF) and also by preventing the challenges like restricted policies and also by improving the transparency and produce which are delivered. And The Key Government policies supporting Supply chain Technology in India are listed in Table 2.

Table 2. Key Government Initiatives in Supply Chain Management

Schemes (Launch Year)	Description
Make in India (2014)	The Make in India Campaign was started to encourage both domestic and foreign businesses to manufacture in India in an effort to turn the country into a global centre for manufacturing.
Sagarmala Project (2015)	The Sagarmala Project seeks to support port-led development, improve port connectivity and update India's infrastructure. This enhances the margin of supply chain enabling smoother trade flow.
Goods and Services Tax (GST) Implementation (2017)	For the Indian Supply chain, the implementations of GST were revolutionary. GST streamlined the tax system by substituting a single tax for several states which cut down one time expression for logistics. As a result, warehouse and transportation networks were more effective.
Bharatmala Pariyojana (2017)	The goal of this extensive road building program is to increase effectiveness of road transportation nationwide. Though improving connectivity to far-flung locations, building new roadways, and renovating current routes
National Logistics Policy (2020)	It focuses on standardizing logistics processes, leveraging technology, and fostering greater coordination among various stakeholders in the supply chain.

Source: Authors' Compilation (2025)

Conclusion

The Market demand and the value for new innovations in supply chain is growing drastically in India as well as in world wide. Majority of the companies like Fasal, Farm2farm, Cropin are involved in agricultural supply chain management. The change in logistics and procurement of the perishable goods from the farmers may list some problems to the farmers and also to the procurement agencies but these practices help with wide range for delivering the products and handling a large amount of logistics at a time for different locations. The Government of India also provides many schemes to help with financial conditions for the farmer's and new innovators to dive deeper into supply chain technology. Even with all of these

innovations in supply chain management, the Indian agricultural sector faces major problems like lack of liquidity for growers, maintenance of shelf life of the products after procurement, lack of technical knowledge for handling the supply chain management etc. and therefore, an holistic approach that integrates technical innovations, infrastructure development farmers empowerment and policy reforms can create an transparent and profitable environment.

References

1. <https://veritech.in/blog/>
2. <https://www.edengreen.com/blog-collection/blockchain-technology-in-agriculture>
3. <https://www.tvsscs.com/how-are-technological-innovations-transforming-the-supply-chain-in-india/&ved=2ahUKEwjewJnwge-PAxXKSWwGHQGNM4EQFnoECBoQAQ&usg=AOvVaw26nys9cFTAUWGNPjeXr5PM>
4. <https://tracextech.com/food-supply-chain-in-india/&ved=2ahUKEwiVsI6NhO-PAxVWZWwGHQmtA9wQFnoECCIQAQ&usg=AOvVaw2qhooaRntwrWBqAt6SI0PA>
<https://www.precedenceresearch.com/agriculture-supply-chain-management-market>

Volume: 05 Issue No: 12

MOLECULAR MARKERS IN SHEEP AND GOAT BREEDING: A MODERN TOOL FOR GENETIC IMPROVEMENT

Article ID: AG-V05-I12-115

***Dr. S. Vinothraj, Dr. S. Rajesh Kumar, Dr. T. Geetha, Dr. A.S. Selvaramesh and
Dr. C. Manivannan**

Department of Animal Genetics and Breeding

Veterinary College and Research Institute, Udumalpet- 642 205, TANUVAS, India

*Corresponding Author Email ID: vinothen90@gmail.com

Introduction

Sheep and goats are integral components of the Indian livestock sector, particularly in arid and semi-arid regions. They provide livelihood security to small and marginal farmers through meat, milk, fibre, manure, and quick returns on investment. However, productivity of sheep and goats is often low due to slow genetic improvement, indiscriminate breeding, and environmental stress. Traditional selection based on physical appearance and performance records takes many years and is strongly influenced by feeding, management, and climate.

In this context, **molecular markers** have emerged as powerful tools to accelerate genetic improvement in sheep and goats by enabling accurate selection at the DNA level.

What are Molecular Markers?

Molecular markers are specific sequences of DNA that reveal genetic differences among animals. These markers are inherited from parents to offspring and remain unchanged throughout the life of the animal. Since molecular markers are not influenced by environmental factors, they provide reliable information about the genetic potential of an animal even at an early age. Simply stated, molecular markers act as **genetic signboards** that help breeders identify animals carrying desirable genes for growth, reproduction, milk production, and disease resistance.

Types of Molecular Markers Used in Sheep and Goats

Several molecular marker systems have been developed over the years:

Microsatellite Markers (SSR)

Microsatellites consist of short, repeated DNA sequences and are highly polymorphic. They are widely used for:

- Genetic diversity analysis
- Breed characterization
- Parentage verification

These markers played a crucial role in documenting indigenous sheep and goat breeds in India.

Single Nucleotide Polymorphisms (SNPs)

SNPs represent single base pair changes in DNA and occur abundantly throughout the genome. Due to their high stability and automation potential, SNPs are extensively used in:

- Marker-assisted selection
- Genomic selection
- Genome-wide association studies (GWAS)

SNP-based chips are now becoming available for sheep and goats.

RAPD and AFLP Markers

These markers were used in early genetic studies but are now limited due to reproducibility issues and lower precision compared to SNPs.

Important Genes Identified in Sheep and Goats

Genes Related to Growth and Meat Production

Growth and carcass traits are economically important in small ruminants. Molecular studies have identified several candidate genes such as:

- **Growth Hormone (GH)** gene
- **Insulin-like Growth Factor-1 (IGF-1)**
- **Myostatin (MSTN)** gene, which regulates muscle development

Animals carrying favorable variants of these genes show better body weight gain and meat yield.

Genes Influencing Reproductive Performance

Reproductive efficiency determines flock profitability. Molecular markers have helped identify major fecundity genes:

- **BMP15 (Bone Morphogenetic Protein 15)**
- **GDF9 (Growth Differentiation Factor 9)**
- **BMPR1B (FecB gene)** in sheep

These genes are associated with increased ovulation rate and litter size, enabling selection of more prolific ewes.

Genes Affecting Milk Yield and Quality

In dairy goats, milk production and quality are important traits. Molecular markers linked to:

- **α -casein (CSN1S1)**
- **β -casein genes**

Associated with higher milk yield, better protein content, and cheese-making quality.

Genes Related to Disease Resistance

Disease outbreaks cause major economic losses in small ruminant farming. Molecular markers linked to:

- **Major Histocompatibility Complex (MHC) genes**
- **PRNP gene** for scrapie resistance in sheep

help in identifying naturally disease-resistant animals, reducing dependency on drugs and vaccines.

Applications of Molecular Markers in Sheep and Goat Breeding

Marker-Assisted Selection (MAS)

MAS allows breeders to select animals carrying desirable genes at an early age, even before the trait is expressed. This reduces generation interval and speeds up genetic improvement.

Improvement of Prolificacy

Identification of high-fecundity genotypes helps increase lambing and kidding rates, leading to higher returns per animal.

Conservation of Indigenous Breeds

Molecular markers help assess genetic diversity and prevent inbreeding in native breeds such as Kilakarsal, Vembur, Mecheri sheep and Kanni Adu, Kodi Adu goats.

Parentage and Pedigree Verification

Accurate pedigree recording improves breeding programme efficiency and avoids mating errors.

Advantages of Molecular Marker Technology

- Accurate and environment-independent selection
- Early identification of superior animals
- Faster genetic gain



- Improved disease resistance and productivity

Constraints in Field-Level Adoption

- High cost of DNA testing
- Limited access to laboratories
- Need for trained technical manpower
- Low awareness among farmers

Volume: 05 Issue No: 12

ROLE OF DIGITAL AGRICULTURE IN ENHANCING SUSTAINABILITY IN FARMING

Article ID: AG-VO5-I12-116***¹Jaiky Verma, ¹Akshay Singh and ¹Aditya Singh**

¹PhD Scholar, Department of Agricultural Extension, Mahatma Gandhi Chitrakoot Gramodaya Vishwavidyalaya Chitrakoot, Satna, M.P. 485334, India

*Corresponding Author Email ID: vermajaiky43@gmail.com

Abstract

Many developing economies still rely heavily on agriculture, but it faces significant obstacles like climate change, water scarcity, declining soil fertility, and shrinking farmland. Digital agriculture, or the incorporation of digital technologies into farming, has become a viable way to meet the increasing demand for food in a sustainable manner. Digital agriculture makes data-driven decisions that improve productivity, resource efficiency, and environmental protection by integrating tools like sensors, drones, AI, IoT, and mobile platforms. By maximizing input use, conserving resources, enhancing market access, and empowering smallholders, it promotes sustainable farming in all spheres—environmental, economic, and social. Its adoption can be accelerated by strategic investments, policy support, and capacity building, even in the face of obstacles like limited infrastructure, cost, and digital literacy. In the end, digital agriculture offers a revolutionary route toward future food systems that are resilient, inclusive, and sustainable.

Keywords: AI, IoT, smart farming, digital agriculture, sustainability, and precision farming

➤ Introduction

Many economies rely heavily on agriculture, especially in developing nations where a sizable section of the population makes their living from farming. However, the agricultural industry is facing previously unheard-of difficulties like climate change, dwindling arable land, deteriorating soil fertility, a lack of water resources, a labour shortage, and heightened market competition. In order to feed the world's expanding population, more food must be produced

sustainably. Digital agriculture, a contemporary strategy that combines digital technologies with conventional farming methods, has emerged as a result of this dual challenge of raising productivity while preserving environmental balance.

The use of digital tools, such as sensors, mobile applications, drones, robotics, artificial intelligence (AI), machine learning (ML), blockchain, Internet of Things (IoT), and geographic information systems (GIS), to enhance agricultural processes is known as digital agriculture, sometimes referred to as smart farming or e-agriculture. These technologies make it possible for farms to make data-driven decisions, which improves socioeconomic outcomes for farmers, reduces environmental impact, and makes better use of resources. Digital agriculture has the potential to drastically change conventional agriculture into a more effective, resilient, and sustainable system by offering precise, real-time information about crops, soil, weather, inputs, and markets.

This article's goal is to examine how digital agriculture can improve farming's sustainability by highlighting its advantages, effects, uses, difficulties, and potential future developments.

Core components of digital agriculture include:

Sensors, GPS units, drones, and satellite imaging are used for data collection. Mobile applications, dashboards, and advisory systems that provide practical suggestions are used for decision support.

- **Automation:** robotic harvesting, smart cars, irrigation automation
- **Digital platforms:** for purchasing inputs, connecting markets, providing financial services, and exchanging knowledge.

Digital agriculture ensures that farmers benefit from **precision, efficiency, timeliness, and predictability**—which are crucial for sustainable farming.

➤ **Sustainability in Agriculture and the Digital Link**

Producing food in a way that maintains natural resources, safeguards the environment, sustains farmer livelihoods, and satisfies current needs without jeopardizing those of future generations is known as sustainable agriculture. There are three main ways that digital agriculture promotes sustainability:

Dimension

Contribution of Digital Agriculture

Environmental Sustainability : minimizes input waste, conserves water, safeguards the health of the soil, and uses few chemicals to control pests.

Economic Sustainability : Boost market access, lower cultivation costs, increase yield, and increase farm income

Social Sustainability : increases knowledge access and encourages women, young people, and small farmers to participate.

➤ **Digital Agriculture's Contribution to Improving Sustainability.**

i. Precision Farming and Resource Optimization

Using digital tools, precision farming applies pesticides, fertilizers, and water only where and when necessary. For instance:

- GPS-guided tools facilitate precise field mapping and sowing.
- Soil sensors detect moisture and nutrient levels.

ii. Climate-Smart Decision Making

Timely access to weather data is crucial because of the unpredictability of the climate. Digital platforms offer:

- Short-term and seasonal weather forecasts
- Early warning systems for droughts, heat waves, floods, and pest outbreaks.
- Suggestions for irrigation and planting dates.

iii. Smart Water Management

One of the most urgent issues facing agriculture is water scarcity. Effective water use is encouraged by digital agriculture through: ★ ★ ★ ★

- Scheduling irrigation using remote sensing.
- Drip irrigation systems with Internet of Things capabilities.
- Automatic irrigation controllers and soil moisture sensors.
- Monitoring groundwater levels and crop water requirements in real time.

iv. Pest and Disease Management

Early pest and disease detection and quick control are made possible by digital tools through:

- Apps for mobile pest diagnosis.
- AI-driven image analysis to identify crop diseases.
- Using drones to apply pesticides precisely.
- Models for predicting pests that notify farmers prior to outbreaks.

v. Links to the Market and Improved Price Realization

By linking farmers with markets, digital agriculture transcends the field:

- Produce can be sold directly through e-commerce platforms.
- Daily market price information is available through smartphone apps.
- Transparency and traceability are guaranteed by blockchain technology.
- Support for online logistics lowers post-harvest losses.

vi. Financial Inclusion and Risk Management

Farmers are economically empowered by digital financial services like microloans, crop insurance, online payments, and agri-credit. Digital records enable weather-indexed crop insurance, which expedites claim settlement and shields farmers from climate-related losses.

vii. Knowledge Sharing and Extension Services

Digital platforms make it possible for traditional extension systems to physically reach every farmer. Farmers have access to:

- Local language mobile advisory services.
- Webinars and online training videos.
- Digital hotlines for immediate assistance.
- Knowledge networks rooted in communities.

➤ Social and Economic Impact of Digital Agriculture

Digital agriculture does not only improve farm productivity; it creates broad socio-economic benefits:

i. Empowerment of Small and Marginal Farmers

Digital tools give small farmers access to markets, financial services, and scientific knowledge—areas that have historically been dominated by large farmers.

ii. Opportunities for Youth and Women

Drone operations, e-marketing platforms, agri-tech companies, and digital service centers reduce unemployment and migration by providing rural women and youth with jobs and income.

iii. Cost Reduction and Higher Profitability

Reduced crop loss, better value chain integration, and efficient input use all lower production costs and boost profitability.

iv. Improved Food Security

Long-term food security is influenced by both increased productivity and decreased environmental deterioration.

v. Barriers to Adoption of Digital Agriculture

Despite the enormous advantages of digital technologies, their uptake is uneven because of a number of obstacles:

Category	Challenges
Technological	Limited rural internet Connectivity, Poor digital infrastructure
Financial	High cost of devices, software, and maintenance
Social	Limited digital literacy among farmers, language barriers
Institutional	Lack of training programs and extension Support.
Cultural	Resistance to new technologies and preference for traditional methods

➤ **Strategies to Accelerate Scaling of Digital Agriculture**

The following actions are crucial to guaranteeing widespread adoption:

- i. Improving digital infrastructure and internet access in rural areas.
- ii. Government subsidies for precision farming equipment and digital tools.
- iii. Farmers' training in digital literacy and capacity-building initiatives.
- iv. Using public-private partnerships (PPP) to create reasonably priced Agri-Tech solutions.
- V. Regional language-specific content for digital advisory services.
- vi. Involvement of youth in rural digital entrepreneurship initiatives.
- vii. Endorsing farmer-producer organizations (FPOs) as facilitators of technology.

➤ **Future Outlook**

Future developments in digital agriculture are anticipated to further transform farming. Robots powered by artificial intelligence, self-driving tractors, automated greenhouses, digital twins of farms, and fully integrated smart supply chains are examples of trends that might soon become commonplace. Digital agriculture will be a key component of sustainable, climate-resilient farming since climate change continues to threaten food systems.

The future agricultural landscape will likely be:

- **Data-rich**
- **Technology-driven**
- **Environmentally responsible**
- **Inclusive for farmers of all scales**

Conclusion

A revolutionary strategy that balances productivity and sustainability is digital agriculture. Digital tools assist farmers in maximizing input utilization, conserving natural

resources, managing climate variability, minimizing losses, gaining access to markets, and increasing economic returns by using data and technology to inform decisions. Additionally, by enhancing farmer knowledge, empowering smallholders, and generating jobs in rural areas, digital agriculture fosters social sustainability.

Adoption presents certain difficulties, but overall, the advantages are unquestionably greater than the drawbacks. A sustainable, resilient, and prosperous agricultural future can be greatly enhanced by digital agriculture with the right policy support, investments in digital infrastructure, and farmer-oriented capacity building.

References

- Balasundram, S. K., Shamshiri, R. R., Sridhara, S., & Rizan, N. (2023). The role of digital agriculture in mitigating climate change and ensuring food security: an overview. *Sustainability*, 15(6), 5325.
- Sridhar, A., Balakrishnan, A., Jacob, M. M., Sillanpää, M., & Dayanandan, N. (2023). Global impact of COVID-19 on agriculture: role of sustainable agriculture and digital farming. *Environmental Science and Pollution Research*, 30(15), 42509-42525.
- Bhaskara, S., & Bawa, K. S. (2021). Societal digital platforms for sustainability: Agriculture. *Sustainability*, 13(9), 5048.
- Adewusi, A. O., Asuzu, O. F., Olorunsogo, T., Iwuanyanwu, C., Adaga, E., & Daraojimba, D. O. (2024). AI in precision agriculture: A review of technologies for sustainable farming practices. *World Journal of Advanced Research and Reviews*, 21(1), 2276-2285.
- MacPherson, J., Voglhuber-Slavinsky, A., Olbrisch, M., Schöbel, P., Dönitz, E., Mouratiadou, I., & Helming, K. (2022). Future agricultural systems and the role of digitalization for achieving sustainability goals. A review. *Agronomy for Sustainable Development*, 42(4), 70.
- Khose, S. B., Dhokale, K. B., & Shekhar, S. (2023). The role of precision farming in sustainable agriculture: advancements and impacts. *Agriculture and Food E-newsletter*, 5(9), 115-119.
- Singh, N. K., Sunitha, N. H., Tripathi, G., Saikanth, D. R. K., Sharma, A., Jose, A. E., & Mary, M. V. (2023). Impact of digital technologies in agricultural extension. *Asian Journal of Agricultural Extension, Economics & Sociology*, 41(9), 963-970.

Volume: 05 Issue No: 12

FEATURES OF SEED PRODUCTION IN TRADITIONAL RICE VARIETIES BY ORGANIC FARMING

Article ID: AG-VO5-I12-117

Dr. C. Sivaranjani¹, Dr. R.Vinoth² and Dr. J. Gokulakrishnan³¹Senior Research Fellow, Dept. Soil Science and Agrl.Chemistry²Teaching Assistant (PBG), Department Genetics and Plant Breeding³Associate Professor (PBG), Department Genetics and Plant Breeding

Institute of Agriculture, TNAU, Kumulur, Tamil Nadu, India

*Corresponding Author Email ID: sranjani0492@gmail.com

Introduction

Seed production is of paramount importance to farmers because quality seeds are the most vital and cost-efficient input for agricultural production, directly determining the efficacy of all other inputs like fertilizers, pesticides, and irrigation. The use of quality seed alone can contribute an increase in productivity of at least 15-25%. Seed production is vital for farmers as it directly determines crop yield and quality, with high-quality seeds alone contributing to 20–25% of output. It ensures genetic purity, vigor, and the ability to withstand pests, diseases, and adverse conditions, leading to better growth, higher market prices, and increased income. Ultimately, access to improved seeds is fundamental for a farmer's productivity and for meeting the nation's food security needs.



Quality seed production which follows efficient certification procedures plays a major role in the increase of food production of our country. To ensure this, the Government has prescribed standards and has brought in seed production techniques, testing, certification and marketing procedures through the Seeds Act, 1966. In the current scenario, the demand for good quality certified seeds far exceed the availability in the market. This section provides details about production and procurement of good quality seeds.

Key Benefits of Quality Seed Production for Farmers

- **Increased Yield and Productivity:** Quality seeds of improved/hybrid varieties carry the genetic potential for higher yields, which translates to increased food production and better income for farmers. The green revolution was largely a "seed revolution".
- **Optimal Use of Resources:** Good seeds respond better to inputs such as water, fertilizer, and improved management practices. Using poor-quality seeds can nullify the benefits of these other, often more expensive, inputs, leading to wasted time and resources.
- **Pest and Disease Resistance:** Modern quality seeds are often bred to be resistant to prevalent pests and diseases. This minimizes the need for chemical sprays, reduces environmental impact, and safeguards the crop during critical growth stages.
- **Climate Resilience and Adaptability:** Seed production programs focus on developing varieties that are suited to diverse and changing agro-climatic conditions, including tolerance to drought, heat, and salinity. This helps farmers mitigate risks associated with climate change and environmental stresses.
- **Assured Quality and Uniformity:** Seeds produced under controlled, formal seed production systems adhere to quality standards (genetic and physical purity, high germination rate, freedom from disease). This ensures a uniform crop stand, predictable growth, and consistent maturity, which is valuable for harvesting and marketing.
- **Risk Mitigation and Food Security:** A robust seed supply system, including local seed production and seed banks, ensures the timely availability of seeds after natural calamities like floods or droughts, allowing farmers to quickly resume agricultural production and ensuring household food security.
- **Economic Benefits:** The cost of seed is a relatively small portion of the total cost of cultivation, but it has a disproportionately large impact on the final yield and market

value. Investing in quality seeds boosts farmer income through better quality produce and higher market prices.

In essence, seed production provides the fundamental foundation for sustainable and profitable agriculture, empowering farmers to achieve better outcomes with their land and efforts.

PADDY (*Oryza sativa*)

Paddy (*Oryza sativa*) is a well known cereal belonging to the family Gramineae. It is the second important cereal next to wheat in Asia. It is a staple food for more than 60% of the population. Paddy seed production can be taken up in all the seasons like December - January, April - May, May - June, June - July, July – August and September – October.

Method of seed production

Paddy is a self-pollinated crop with cross pollination to the extent of 0 – 4%. The crop should be raised in isolation and seeds are allowed to set by open- pollination. To maintain the varietal purity an isolation distance of 3 metres is maintained in both certified and foundation stage of seed production. If isolation by space is not possible then the time isolation of 21 days can be given.

Site Selection

The land selected should not be cultivated with the same crop in the previous season. This standard requirement is applicable for both nursery and main field. Land should be free of weeds. Land should be fertile with good irrigation and drainage facilities and with good sunlight and aeration.

Green Manuring

Green manure crops like sunhemp, daincha, Indian indigo etc., should be raised in the main field and incorporated into the soil 45 – 50 days after sowing. The plants should be allowed to decay in the water for ten days and then ploughed. The decomposed plants convert the unavailable forms of calcium, phosphorus and micronutrients present in the soil into an easily available form. Application and ploughing of green leaves into the soil will also increase the nitrogen content of the soil. Leaves of Neem, Pongamia, Gliricidia etc., are used as green leaf manure.

Oil seed cakes like neem cake and groundnut cake can also be applied to meet the nitrogen needs of the crop. In paddy neem cake is applied as basal manure @ 60 kg/acre (150

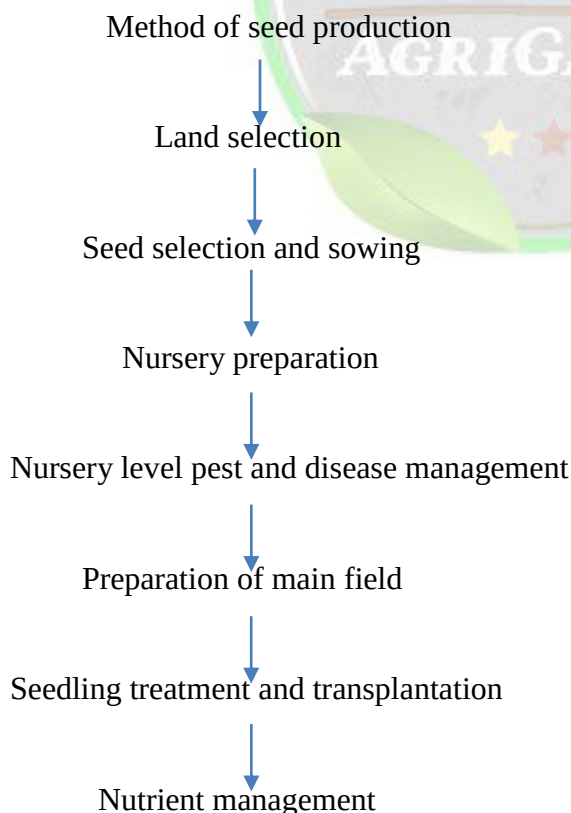
kg/ha) and as top dressing @ 25 kg/acre (60 kg/ha) or groundnut cake is applied as basal manure @ 40 kg/acre (100 kg/ha) and as top dressing @ 10 kg/acre (25 kg/ha).

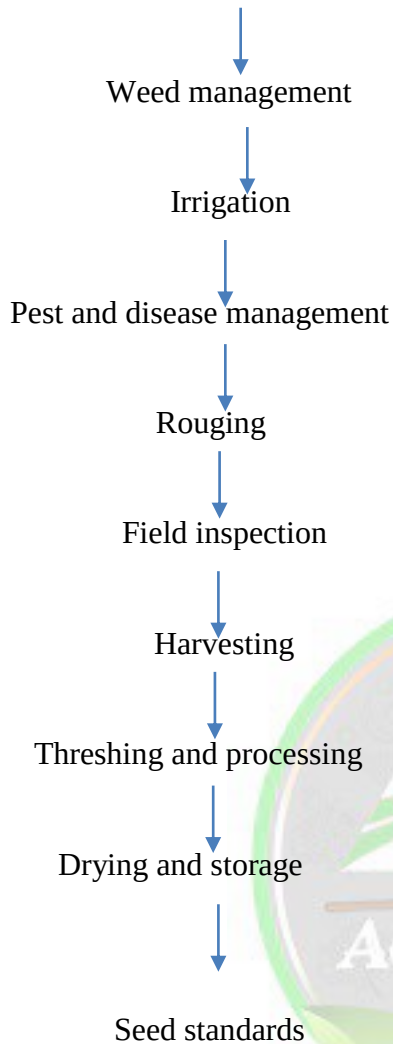
Seed Selection and sowing

Seeds used for the seed production should be of good quality certified seeds from an authentic source. Seeds should be healthy with good germination percentage. Seed rate may range from as low as 5 kgs / acre if SRI techniques are used to 30 kgs / acre under some dryland conditions. It also depends on the exact method used in cultivation. Quality seeds can be separated from unviable seeds by soaking in water.

The unviable and damaged seeds that float on the water surface should be removed and the good quality seeds that sink should be used for cultivation. If there is excess of chaffy seeds in the selected seed lot, take some water in a vessel and drop an egg in it and keep adding salt till the egg reaches surface. Then add seeds to the water and remove the chaffy unviable seeds that float on the surface of the water. Then wash the selected seeds in good water for 2 – 3 times to remove the salt completely. Otherwise it will interfere with germination. Selected seeds should be treated in order to improve the germination potential, vigour and resistance to pest and diseases.

Flow chart for seed producing structure



**Seed treatment:**

Selected seeds should be treated in order to improve the germination potential, vigour and resistance to pest and diseases.

1. Selected seeds should be treated with cow dung and cow's urine solution (0.5 kg fresh cow dung + 2 litres of cow's urine + 5 litres of water). Soak the seeds in water for 10 - 12 hours and then in the cow dung solution for 5 – 6 hours. Shade dry the seeds before sowing.

2. Selected seeds should be tied in small cloth bags and soaked in cow's urine solution (500 ml cow's urine in 2.5 litres of water) for 30 minutes and shade dried before sowing.

3. Soak the seeds required for 1 hectare in sweet flag extract (1.25 kg of sweet flag rhizome powder in 6 litres of water) for 30 minutes and shade dry before sowing.

4. Biofertilizers like *Azospirillum* / *Azotobacter* / *Pseudomonas* @ 10 gms / kg of seeds mixed with 20 ml cooled rice gruel can be used. Mix this with the sprouted paddy seeds. Shade dry the seeds for 30 minutes before sowing.

Seedling treatment and transplantation. Before transplanting the seedlings are treated against pest and disease attack.

1. Treat seedlings with ash and neem seed mixture. Paddy seedling bundles should be kept in small plots of standing water mixed with ash and neem seed powder mixture (1 kg ash and 500 gms of neem seed powder for 50 bundles of seedlings) for 30 minutes to an hour. Seedlings treated with this mixture produce a crop free from pests and diseases
2. Soak the seedlings in groundnut cake and neem cake solution before transplanting to make the seedlings less vulnerable to pest attack.
3. Paddy seedlings can also be dipped in solution of Amirthakaraaisal /Panchagavyam / Jeevamrut). These are preparations which include products from the cow such as - cowdung, cow urine, ghee mixed with substances such as coconut water, jaggery, banana etc. in varied proportions.

The optimum age of seedlings for transplanting is 18 – 22 days for short, 25 – 30 days for medium and 35 – 40 days for long duration varieties. 2-3 seedlings per hill are transplanted at a depth of 3 cm. The spacing between the seedlings will vary according to the variety cultivated (Short duration – 15 x 10 cm, Medium duration – 20 x 10 cm and Long duration – 20 x 15 cm). Before transplanting clip off the tips of the seedlings to facilitate uniform growth

During final ploughing cow dung 5 – 6 tonnes/acre (12 – 15 tonnes/ha) / goat dung 5 tonnes/acre (12.5 tonnes/ha) / poultry waste 2 tonnes/ acre (5 tonnes/ ha) / pig dung 1 tonne/acre (2.5 tonnes/ha) can be applied and incorporated into the soil. To meet the nitrogen need biofertilizers like *Azospirillum* / *Azotobacter* /*Phosphobacteria* are also used.

Growth regulators like Panchagavyam @ 3% can be applied at the tillering and bootling stages for coarse varieties and at the bootling stage alone for fine varieties. Amithakaraaisal @ 500 litres/acre (1250 litres/ha) should be mixed with irrigation water.

Benefits of Traditional Organic Rice Seeds

- **Enhanced Quality:** Improved aroma, taste, and nutritional value.
- **Climate Resilience:** Better resistance to drought and floods.

- **Medicinal Value:** Many varieties possess therapeutic properties (e.g., diabetes management).
- **Sustainability:** Supports farmer self-reliance and environmental harmony.

Conclusion:

In conclusion, the pre- and post-harvest package of practices for traditional rice cultivation under organic farming presents a comprehensive framework for sustainable agriculture. By integrating organic principles throughout the cultivation cycle, farmers can optimize yields, preserve environmental integrity, and meet the demands of conscientious consumers. Embracing these practices not only ensures the quality and aroma of the rice but also fosters resilience in farming communities and contributes to a healthier planet. As we move forward, continued research, education, and collaboration will be essential to further refine and expand these practices, paving the way for a thriving future in organic traditional rice cultivation.

References

- Chakraborty, S. (2019). Evaluation of Indigenous Aromatic Rice Cultivation: An Overview on Tulaipangi Rice in West Bengal, India. *International Journal of Research and Analytical Reviews (IJRAR)* 6 (2), 814-821
- ICAR-NRRI Annual Report 2022-2023. National Rice Research Institute, Indian council of Agricultural Research, Cuttack, India.
- Kumar, A., Avasthe, R. K., Babu, S., Singh, R., Verma, G., Dhaka, A. K., & Hasanain, M. (2021). Jeevamrut: A low cost organic liquid manure in organic farming for sustainable crop production. *Kerala Karshakan E Journal*, 9, 32-34.
- Saryoko, A., Kusumawati, S., & Pohan, A. (2021, February). Seed treatment using biofertilizer to improve plant growth and yield performances of upland rice cultivars under various planting densities. In *IOP Conference Series: Earth and Environmental Science* (Vol. 648, No. 1, p. 012028). IOP Publishing.

THE SILENT BANK BENEATH OUR FIELDS: WHY GROUNDWATER FOR IRRIGATION MUST BE VALUED

Article ID: AG-VO5-I12-118**Nikhil Govind Malali^{1*} and Dr. V. Karthick²**

¹M.Sc. Scholar, Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India.

²Assistant Professor, Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore – 641003, Tamil Nadu, India.

*Corresponding Author Email ID: nikhilmalali0001@gmail.com

Abstract

Groundwater has quietly powered irrigated agriculture for decades, but rapid deepening of wells, rising pumping costs and land subsidence now signal serious overuse^{1,7,10}. This article discusses how unpriced or underpriced groundwater encourages wasteful extraction, threatening farm incomes, rural infrastructure and future food security^{2,3,7-9}. A non-technical narrative is used to explain four economic valuation tools Residual Value Method, Production Function Approach, Contingent Valuation Method and Choice Experiment, that help quantify the worth of irrigation water at farm and system level³⁻⁶. The article highlights hidden social costs such as failed wells, higher energy use and loss of options for future generations, and presents real-world examples where recharge structures, efficient irrigation and better pricing have helped stabilize aquifers⁷⁻⁹. It concludes that treating groundwater as an economic and ecological inheritance is essential to achieve more income, more resilience and more future security per drop^{1-3,7}.

Key words: Groundwater, Irrigation, Economic valuation, Farmers, Water pricing, Sustainability

Introduction

Across rural landscapes, every running pump and green field tells the same story: groundwater has become the most dependable source of irrigation water for millions of farmers^{1,2}. By allowing crops to be grown beyond the limits of rainfall and canal schedules, this invisible resource has supported agricultural growth and helped stabilize farm incomes and food

supplies¹. However, the very success of groundwater-based irrigation has created a new crisis. In many regions, wells are being drilled deeper each year, pumping hours are increasing and electricity or diesel costs are rising, yet the water they lift is steadily declining⁷⁻⁹. Land subsidence, damaged infrastructure and drying shallow wells show that withdrawals are exceeding natural recharge¹⁰. Farmers bear immediate financial losses when wells fail, while society bears long-term ecological and intergenerational costs^{2,7}.

Despite this, groundwater is often treated as if it were free, with farmers paying mainly for energy rather than for the water itself⁷⁻⁹. This disconnect between physical scarcity and economic signals encourages over-extraction and discourages investment in water-saving technologies^{3,8,9}. The purpose of this article is to explain, in simple language, why economic valuation of groundwater used for irrigation is important, how key valuation methods work and how such information can guide better policies, technologies and community action²⁻⁴.

Contents

Groundwater: A silent bank account

Groundwater behaves like a savings account under farmers' fields: when withdrawals exceed deposits, the balance shrinks and eventually runs out. Decades of motorization, cheap or flat-rate electricity and promotion of water-intensive crops have led to rapid growth in tubewell irrigation, but in many aquifers, withdrawals now far exceed recharge⁷⁻⁹. Farmers respond to falling water tables by deepening wells, installing more powerful pumps or drilling new boreholes, all of which demand more capital and energy^{7,8}.

These responses buy time but do not solve the underlying imbalance. Poor and small farmers, who cannot afford repeated investments, are often the first to lose access when shallow wells fail⁷. At the same time, communities and governments must cope with cracked roads, damaged canals and increased flood or drought risks as groundwater storage and land stability are altered^{9,10}. Recognizing groundwater as a finite common resource rather than an individual's private stock is therefore essential for long-term agricultural and rural stability^{2,3}.

Why economic valuation is needed?

In many settings, farmers rarely pay a direct price for groundwater; instead, they pay for electricity or diesel to run pumps and for drilling and maintaining wells⁷⁻⁹. When the water itself appears "free", there is little economic signal to conserve it, even though every extra hour

of pumping pushes the water table lower for everyone⁷⁻⁹. Economic valuation provides a way to quantify the benefits generated by groundwater and the costs created by its overuse^{2,3}.

By putting a monetary value on water used for irrigation, valuation helps answer questions such as: Which crops make the best use of scarce water? How much does groundwater contribute to farm income compared with other inputs? How much would farmers be willing to pay for more reliable or cleaner water? Such information is vital for designing crop recommendations, irrigation programmes, electricity pricing and community rules that encourage efficient and equitable use of groundwater³⁻⁵.

1. Residual Value Method

The Residual Value Method starts from a simple farm-budget idea³⁻⁵. First, the total income a farmer earns from a crop is calculated by multiplying yield by market price^{3,5}. Then all non-water costs such as seed, fertiliser, pesticides, hired and family labour, machinery use and land rent are subtracted from this gross income^{3,5}. The remaining surplus, or “residual”, is treated as the value created by irrigation water for that crop and season³⁻⁵.

This method, when applied across different crops or farms, shows how much value each unit of water generates under real farming conditions³⁻⁵. For example, high-value vegetables may produce a much larger residual per unit of water than a low-value, water-intensive cereal grown in the same area^{3,5}. Policymakers and extension workers can use such comparisons to encourage crop choices and irrigation practices that yield more income per drop, especially in water-stressed regions^{3,4}.

2. Production Function Approach

The Production Function Approach views crop yield as the outcome of combining several inputs such as land, labour, seed, fertiliser and water^{3,4}. By examining data on how yields change when water application changes, while holding other inputs constant as far as possible, it estimates the marginal contribution of each additional unit of water^{3,5}.

In practice, statistical models are used to trace a relationship between water use and output^{4,5}. From this relationship, one can calculate the marginal physical product of water and, by multiplying with crop price, its marginal value product^{3,4}. This indicates how much extra income a farmer gains from an extra unit of water at different levels of application and helps identify efficient irrigation levels where the value of extra water just equals its cost^{4,5}. It also shows when additional water becomes wasteful because it adds little to yield^{3,4}.

3. Contingent Valuation Method

The Contingent Valuation Method focuses on the farmers' own perceptions of value⁴. Instead of inferring water's worth only from yields and costs, it asks farmers directly how much they would be willing to pay for improved irrigation services^{4,5}. In a structured survey, farmers are presented with realistic scenarios for example, more reliable water supply, better timing of deliveries, improved water quality or a new community well and then asked their maximum willingness to pay for those improvements^{4,5}.

Carefully designed questions help farmers think about both the income benefits and the reduced risk or stress that dependable water would bring⁴. Responses, when analysed across many farmers, provide estimates of the economic value they attach to different improvements^{4,5}. This method is particularly useful when planning new irrigation projects or service upgrades, because it reveals whether proposed charges are affordable and acceptable, and how strongly farmers value reliability compared with other attributes^{4,5}.

4. Choice Experiment

In a Choice Experiment, farmers are not asked to state a price directly. Instead, they are shown alternative "packages" of irrigation options, each combining different levels of water price, reliability, quantity, quality or institutional arrangements^{4,6}. For example, one option may offer highly reliable water at a higher price, while another offers cheaper but less reliable water. Farmers are asked repeatedly which option they would choose in each set⁶. By analysing the pattern of choices, researchers can estimate the implicit value farmers place on each attribute of water supply^{4,6}.

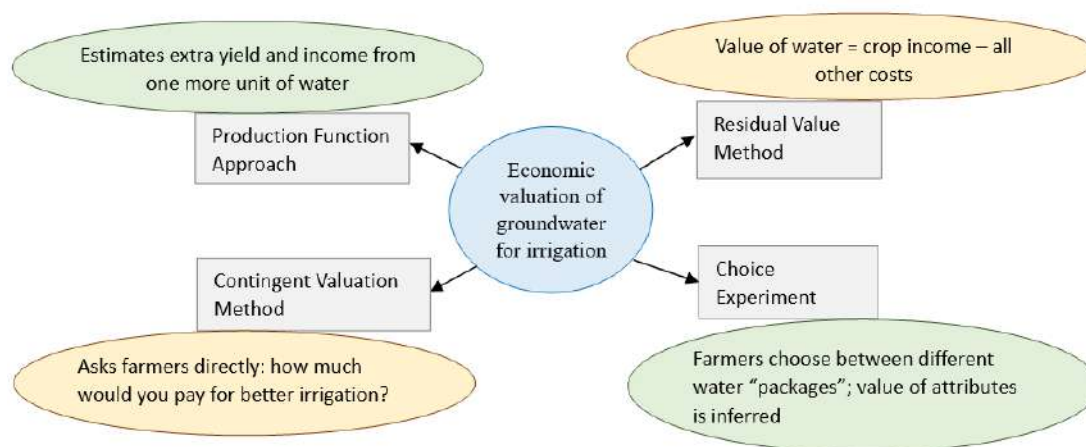


Figure 1. Main economic valuation methods used to estimate the value of groundwater for irrigation.

This method reveals trade-offs: how much extra cost farmers are willing to bear for more reliable water, or how strongly they prefer local control over external management^{4,6}. Choice Experiments thus provide rich information for designing policies and programmes that align with farmers' preferences while encouraging conservation and sustainable use of groundwater^{4,6}

Hidden social costs of groundwater depletion

Although individual farmers make pumping decisions based on their own fields and bills, the effects of groundwater depletion spill over far beyond the farm boundary⁷⁻⁹. When one farmer pumps heavily, the water table can fall for neighbours, forcing them to deepen their wells or abandon them altogether^{7,9}. These costs are often high for small and marginal farmers who lack capital for repeated drilling⁷.

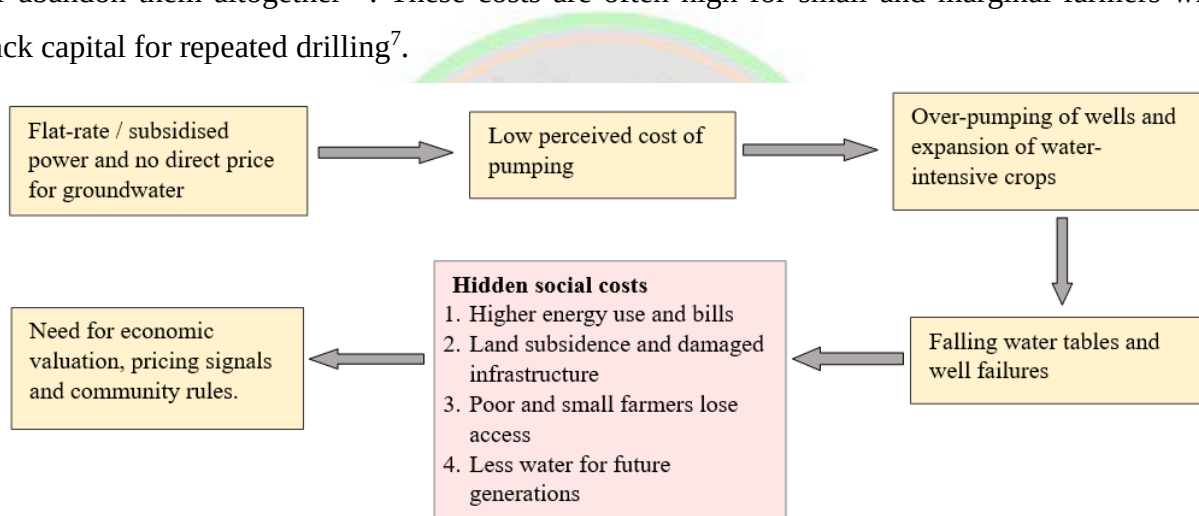


Figure 2. Pathway from "Free" groundwater to depletion and social costs (conceptual).

Falling water tables also raise energy use and costs because pumps must lift water from greater depths⁷⁻⁹. This increases pressure on electricity grids or diesel consumption and contributes to financial stress for farmers and governments^{8,9}. In some areas, excessive withdrawal leads to land subsidence, which damages houses, roads and irrigation canals that entire communities depend on¹⁰. Most importantly, overuse today reduces the volume of water available for tomorrow's farmers, creating an intergenerational burden^{2,7}. These social and environmental impacts seldom appear on a single farmer's cost sheet but are central to any honest valuation of groundwater^{2,3}

Stories of turning the tide

Despite the seriousness of the problem, many communities and governments have shown that groundwater depletion is not inevitable⁷⁻⁹. In several Indian villages, farmers and local organisations have constructed check dams, percolation ponds and contour trenches to capture monsoon runoff and enhance groundwater recharge⁹. Over time, wells that had been drying began to recover, and farmers could reduce pumping costs and shift to a more diversified cropping pattern⁹.

Elsewhere, policies that recognise water's value have encouraged more efficient use⁷⁻⁹. In parts of Australia's Murray–Darling Basin, irrigation water use is measured and linked to secure, tradable rights, allowing water to move to higher-value uses through markets⁴. Farmers facing higher water prices have adopted drip and sprinkler systems, changed crops and improved scheduling to get more output from less water^{6,8}. In other regions, including India and California, experiments with community water budgeting, limits on pumping and comprehensive groundwater legislation show that when stakeholders understand both the benefits and the risks, they can design local rules and institutions to protect their shared aquifers⁷⁻⁹.

From “more crop per drop” to “more future per drop”

For many years, the slogan “more crop per drop” captured the goal of increasing water productivity in agriculture. In the face of groundwater depletion, this idea needs to expand to “more income and more future per drop”^{2,3,7}. It is not enough to maximise yield in a single season if doing so undermines the aquifer that sustains farming over decades^{2,7,9}.

Economic valuation supports this broader vision by revealing which combinations of crops, technologies and management bring the highest long-term benefits from limited water³⁻⁵. When water's value is visible, farmers have stronger incentives to adopt water-saving methods, and policymakers are better equipped to design support programmes and regulations^{3,8,9}. Communities, too, can use valuation insights to negotiate fair sharing arrangements and to justify investments in recharge and conservation⁷⁻⁹. In this way, economic tools become allies of ecological wisdom, reminding everyone that what is precious should not be wasted^{2,3}.

Conclusion

Groundwater has quietly underpinned irrigated agriculture and rural livelihoods for decades, yet its overuse now threatens the very security it once provided^{1,2,7}. Treating groundwater as a free or low-cost input has led to excessive pumping, rising energy use, failed

wells, land subsidence and loss of options for future generations⁷⁻¹⁰. Economic valuation does not reduce water to mere numbers; instead, it provides a structured way to recognise how much groundwater contributes to farm income, risk reduction and community wellbeing²⁻⁴.

By using methods such as Residual Value Method, Production Function Approach, Contingent Valuation Method and Choice Experiment, stakeholders can better understand the true worth of irrigation water and the hidden social costs of depletion³⁻⁶. This knowledge can guide crop planning, irrigation technology promotion, electricity and water pricing, and community-based rules that protect aquifers⁷⁻⁹. Ultimately, valuing groundwater as an economic and ecological inheritance is essential to secure more income, more resilience and more future per drop for present and coming generations^{2,3,7}.

References

1. FAO. 2003. The role of water in agricultural development. FAO Water Reports 27, FAO, Rome, 11–30.
2. National Research Council. 1997. Valuing Ground Water: Economic Concepts and Approaches. National Academy Press, Washington, DC, 1–189.
3. FAO. 2004. Economic valuation of water resources in agriculture: From the sectoral to a functional perspective of natural resource management. FAO Water Reports 27, FAO, Rome, 1–210.
4. Speelman S., D’Haese M., Buysse J., D’Haese L. 2013. A comparison of valuation techniques for irrigation water. *Irrig. Drain.* 62(2): 185–193.
5. Omondi S. O. 2014. Economic valuation of irrigation water in Ahero Irrigation Scheme in Kenya. MSc Thesis, University of Nairobi, Nairobi, 1–106.
6. Alcon F., Tapsuwan S., Martínez-Paz J. M., Brouwer R., de Miguel M. D. 2014. Forecasting deficit irrigation adoption using a choice experiment: A case study in southern Spain. *Agric. Water Manag.* 146: 232–239.
7. D’Odorico P. et al. 2022. Solving groundwater depletion in India while achieving food security. *Nat. Sustain.* 5(7): 563–572.
8. Independent Evaluation Group – World Bank. 2021. Addressing groundwater depletion: Lessons from India, the world’s largest user of groundwater. World Bank, Washington, DC, 1–16.



9. Economic Advisory Council to the Prime Minister (EAC–PM). 2024. Addressing Groundwater Depletion Crisis in India. EAC–PM, New Delhi, 1–64.
10. United Nations University–INWEH. 2025. Groundwater Decline and Land Subsidence Threaten India’s Big Cities. UNU–INWEH, Hamilton, Canada, 1–20.

IoT ENABLED SOILLESS AGRICULTURE

Article ID: AG-VO5-I12-119

**Deva Jacob Raj D, Ranjani P, Kalaiyarasi R, Dhanalakshmi V, Francis A, Pragnya Aich
and Juliet Hepziba S***

V. O. Chidambaranar Agricultural College and Research Institute, Killikulam 628 252,
Tuticorin, Tamil Nadu

Correspondence Author Email ID: juliethepziba.s@tnau.ac.in

Abstract

Soilless agriculture encompassing hydroponics, aeroponics, aquaponics, and substrate based systems redefine the protocol to cultivate food crops in a resource constrained world. By decoupling crop growth from traditional soil environments, these systems overcome problems of land degradation, water scarcity, and climatic uncertainty. The integration of the Internet of Things (IoT) adds intelligence and automation, allowing precise control of environmental and nutritional conditions through connected sensors, actuators, and data analytics. IoT-enabled setups monitor key variables such as pH, temperature, humidity, and nutrient concentration in real time, adjusting operations automatically to optimize growth. Artificial intelligence, edge computing, and renewable energy sources now further enhance these smart farms, improving efficiency while reducing environmental impact. Although high costs, power dependency, and network limitations continue to challenge adoption, IoT-based soilless systems represent a transformative step toward sustainable, climate resilient agriculture capable of meeting future food security demands.

Key Words: Soilless agriculture, smart farming, IoT automation, hydroponics, aeroponics, aquaponics.

1. Introduction

The global agricultural landscape faces unprecedented pressure as the world population is projected to reach nearly 10 billion by 2050. Expanding urbanization, soil degradation, and

irregular rainfall are reducing arable land and threatening productivity. Conventional agriculture consumes large quantities of water and labor while remaining vulnerable to climate variability¹. Consequently, alternative farming systems that minimize environmental dependency have gained increasing attention. Soilless agriculture comprising hydroponics, aeroponics, aquaponics, and substrate culture has emerged as a promising solution. These methods deliver essential nutrients directly to plants without soil, leading to faster growth and higher yield per unit area². Hydroponic systems circulate nutrient rich water, aeroponics sprays fine mists to suspended roots, while aquaponics integrates plant and fish cultivation to recycle resources⁹. Such approaches dramatically reduce water use and eliminate soil-borne pests, enabling production in urban rooftops, vertical farms, and regions with poor soil quality³. The technological revolution brought by the Internet of Things (IoT) has elevated soilless farming into a new era of precision and sustainability. IoT integrates sensors, microcontrollers, communication networks, and cloud-based analytics to continuously observe and adjust growing conditions². For instance, IoT-enabled sensors track pH and electrical conductivity (EC), while actuators manage irrigation, nutrient flow, and lighting schedules⁸. Data are processed through platforms such as ThingSpeak giving farmers real time insights into system performance⁸. Practical results already demonstrate IoT's transformative potential. In experimental setups, smart hydroponic systems have achieved up to 80% reductions in water use and more than 50% reduction in cultivation period⁸. Edge computing and automation further allow farms to operate independently of constant internet connectivity⁹. Thus, the combination of IoT and soilless cultivation represents not only a technological innovation but also a vital step toward resource efficient, climate-smart agriculture for the future.

2. SOILLESS AGRICULTURE SYSTEM

2.1. HYDROPONICS

Hydroponics is the foundation of modern soilless cultivation. Plants are rooted in nutrient-enriched water rather than soil, supported by inert media such as perlite, cocopeat, or rockwool⁸. The composition of the solution and its pH are closely managed to supply balanced nutrition. IoT technology enables constant tracking of EC (Electrical conductivity), temperature, and humidity, while microcontrollers automatically regulate pumps, dosing valves, and grow-lights. Cloud dashboards display live readings, giving farmers full control even from remote locations². By eliminating soil-borne diseases and reducing pesticide dependence, hydroponics

produces clean, high-value crops such as lettuce, herbs, and tomatoes³. The reliability and automation provided by IoT reduce manual labor and ensure year round production⁴.

2.2. AEROPONICS

Aeroponics maintains plant roots suspended in air and delivers nutrients as a fine mist, allowing high oxygen absorption and reducing water usage compared to soil based systems⁵. IoT sensors track temperature, humidity, and misting intervals, enabling precise control over the root zone environment⁹. Advanced controllers adjust spray frequency to suit crop stage and environmental changes, helping improve growth consistency⁸. Smart aeroponic systems have also demonstrated significant reductions in resource consumption, particularly water and energy⁹. Since roots are exposed, any failure in misting can damage plants quickly; IoT alerts help detect nozzle blockages or irregular misting cycles before they affect yield⁹. Because of its efficiency and compact design, aeroponics is increasingly used in vertical farming and urban production systems⁸.

2.3. AQUAPONICS

Aquaponics integrates aquaculture and hydroponics to create a circular ecosystem where fish waste becomes plant fertilizer and plants purify water for the fish⁷. Sensors continuously record pH, ammonia, nitrate, and oxygen levels, while automatic pumps and aerators maintain stable conditions. Edge computing units process this data locally, providing immediate corrective action without depending on the cloud⁹. Machine-learning algorithms are now being used to balance nutrient cycling between fish feeding and plant uptake⁹. Aquaponics therefore represents a near-zero-waste food system ideal for urban environments and arid regions.

2.4. SUBSTRATE CULTURE

In substrate based system, plants grow in materials such as cocopeat, sand, or perlite, and nutrient solutions are supplied through IoT-controlled drip irrigation. Sensors measure moisture and EC in the substrate, allowing real-time irrigation adjustments. Organic media promote microbial health, while inorganic ones offer stability and reusability. The combination of IoT automation and suitable media selection ensures precise water management, consistent growth, and minimal leaching losses.

3. IOT SYSTEM ARCHITECTURE IN SOILLESS AGRICULTURE

An IoT ecosystem for soilless farming forms a multi-layered structure connecting sensors, actuators, and analytics platforms (Fig 1).

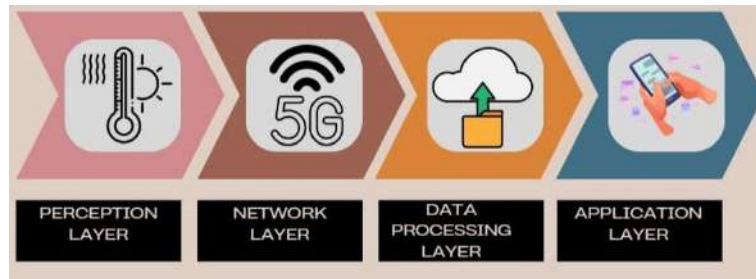


Fig 1 Multi-layered structure of IoT System

Perception Layer: This layer gathers environmental data using sensors for pH, EC, temperature, humidity, light intensity, and dissolved oxygen. Actuators such as pumps, valves, misting nozzles, and LEDs-respond automatically to maintain optimum conditions. Regular calibration or machine-learning-based correction minimizes sensor drift³.

Network Layer: Devices communicate via Wi-Fi or Zigbee for short-range setups and LoRaWAN or NB-IoT for larger farms⁹. Lightweight protocols such as MQTT transfer data efficiently, reducing power use.

Processing Layer: Edge and fog computing handle initial data filtering before sending summarized insights to cloud services. This hybrid approach supports real-time decisions even if connectivity drops.

Application Layer: User dashboards and mobile applications display real time system performance, enabling farmers to automate nutrient dosing, climate control, and irrigation using fuzzy logic or AI based algorithms.

4. ADVANCED TECHNOLOGIES AND TRENDS

4.1. ARTIFICIAL INTELLIGENCE

AI transforms IoT data into predictive intelligence. By learning from historical temperature, humidity, and nutrient patterns, AI models forecast crop stress and automate corrective measures. Image-processing tools can recognize early symptoms of leaf chlorosis, nutrient deficiency or pest damage, ensuring timely corrective action¹⁰. AI driven predictive maintenance also supports equipment reliability by identifying unusual pump or fan behavior before failures occur⁹.

4.2. DIGITAL TWINS

Digital twin technology builds a virtual copy of a physical farm that mirrors live data. Farmers can test "what-if" scenarios changing nutrient strength or light intensity to see simulated

outcomes before applying them. Reinforcement learning algorithms optimize these simulations, finding the best balance between yield and energy use⁹. This reduces costly trial and error in real facilities.

4.3. BLOCKCHAIN AND TRACEABILITY

Blockchain secures farm data by recording every transaction or environmental change in an immutable ledger⁶. Linking IoT sensors with blockchain provides complete traceability from seed to harvest, increasing consumer trust. Smart contracts can verify organic standards or automate payments, simplifying supply chain logistics⁶.

4.4. RENEWABLE ENERGY INTEGRATION

Sustainable energy sources are increasingly important for uninterrupted IoT based farming⁸. Solar powered nutrient pumps and low power microcontrollers reduce reliance on the electrical grid while lowering emissions. Energy aware control algorithms also optimize irrigation and lighting based on available solar power, making off-grid operation practical and cost-effective⁸.

4.5. EDGE AI AND 5G

With 5G connectivity, IoT devices transmit data at lightning speed, allowing sub-second control of nutrient dosing or environmental adjustments⁹. Edge AI performs analytics locally on microcontrollers, reducing cloud latency and preserving data privacy. Future smart farms will use networks of edge intelligent greenhouses collaborating through cloud based coordination to maximize regional productivity.

5. CHALLENGES AND RESEARCH GAPS

Although progress has been rapid, adoption barriers persist. High installation costs for sensors, controllers, and power systems discourage smallholders⁸. Sensor calibration drift can distort nutrient readings, while continuous pump and light operation increases energy demand. Connectivity gaps in rural areas limit automation potential, and incompatible communication protocols hinder device integration. Future research must focus on low cost, modular hardware, self-calibrating sensors, and open-standard platforms for seamless communication. Hybrid networks combining Wi-Fi, LoRa, and cellular links can provide reliable connectivity even in remote farms. Addressing these issues will make IoT-enabled soilless agriculture more inclusive and economically viable worldwide.

6. FUTURE PROSPECTS

The next generation of IoT based soilless systems will emphasize flexibility, intelligence, and sustainability. Modular designs will allow farmers to expand setups easily, while open-source frameworks will reduce software costs. Edge computing will enable faster, offline decision making, ensuring uninterrupted control during connectivity loss. Integrating solar power and energy storage solutions will make farms self sufficient and eco-friendly. Advances in AI and digital-twin modeling will allow systems to learn from past cycles, predicting nutrient needs and environmental responses with minimal human input. These innovations, coupled with affordable sensor technology and interoperable standards, will make smart soilless agriculture a practical solution for ensuring global food security.

Conclusion

The convergence of IoT and soilless cultivation represents a revolution in sustainable agriculture. Real-time sensing, intelligent automation, and predictive analytics enable farmers to produce more food with fewer resources. Hydroponic, aeroponic, aquaponic and substrate culture systems integrated with IoT demonstrate that high yield and environmental responsibility can coexist. While obstacles such as cost and connectivity remain, ongoing improvements in AI, renewable energy, and open platform design are rapidly narrowing these gaps. IoT enabled soilless farming provides a scalable blueprint for future food systems productive, resource efficient, and resilient to climate change.

References

1. El-Kazzaz KA, El-Kazzaz AA. 2017. Soilless agriculture: A new and advanced method for agricultural development. *Agri Res & Tech Open Access J.* 3(2): 555610.
2. Kumar L, Ahlawat P, Rajput P. 2021. IoT for smart precision farming and agricultural systems productivity: A review. *IEAST.* 5(1): 141-146.
3. Joshi D, Nainabasti A, Bhandari R. 2022. A review on soilless cultivation: The hope of urban agriculture. *Arch. Agric. Environ. Sci.* 7(3): 473-481.
4. Monisha N, Maraiah VR, Raju KB. 2023. Analysis of different smart agricultural systems using IoT. *Int. J. Hum.-Comput. Interact.* 2(3): 169-175.
5. Al-Shrouf A. 2017. Hydroponics, aeroponics and aquaponics as compared with conventional farming. *Int. J. Environ. Sci. Dev.* 8(3): 245-250.

6. Hurduzeu G, Medelele DM, Ciobanu A.2022. Sustainable agriculture in EU countries and the potential achievement of SDG-2. Sustainability. 14(23): 15798.
7. Viana CM, Freire D, Pereira P. 2022.Agricultural land systems for supporting food security and sustainable development goals. Sci. Total Environ. 806: 150718.
8. Dutta M, Gupta D, Tharewal S, Goyal D.2025. Internet of Things-based smart precision farming in soilless agriculture: Opportunities and challenges for global food security. IEEE Access. 13: 1-15.
9. Thilakarathne NN, et al. 2025. IoT-enabled smart agriculture: Current status and future directions. Sci. Direct. 240584402500516X.
10. Rathor AS, et al. 2024. AI and IoT-driven systems for sustainable vertical farming. J. Intell. Agric. Syst. 8(2): 41-53.



Volume: 05 Issue No: 12

CROP WILD RELATIVES: IMPORTANCE, CONSERVATION AND UTILIZATION IN CROP IMPROVEMENT

Article ID: AG-VO5-I12-120

***Pranusha P, Gowthami R, Chethan Kumar K B and Nivedhitha S**¹ICAR-National Bureau of Plant Genetic Resources, Regional Station, Hyderabad-500030, India

*Corresponding Author Email ID: pranushaag@gmail.com

Abstract

Crop wild relatives (CWRs) constitute a critical component of global plant genetic resources for food and agriculture. These wild taxa, closely related to cultivated crops, harbor a wealth of genetic variation that has been substantially eroded from domesticated gene pools through intensive selection, and modern breeding. CWRs play a pivotal role in enhancing crop productivity, stability, and resilience by providing genes for resistance to biotic and abiotic stresses, yield improvement, and quality traits. Their strategic conservation and use are indispensable for sustainable agriculture and long-term food and nutritional security.

Keywords: Crop wild relatives, genetic diversity, plant genetic resources, conservation, pre-breeding, food security

Introduction

The narrowing of the genetic base in cultivated crops poses a major threat to global food security. Domestication, selective breeding, and the widespread adoption of genetically uniform high-yielding varieties have substantially reduced intra-specific variation, increasing crop vulnerability to pests, diseases, and environmental stresses. In this context, crop wild relatives (CWRs) wild plant taxa genetically related to cultivated species have emerged as vital reservoirs of adaptive genetic variation (Fig. 1).

Maxted *et al.* (2006) defined CWRs as “wild plant taxa having an indirect use value derived from their genetic relationship to a crop.” They include wild progenitors, conspecific wild populations, and related species within the primary, secondary, or tertiary gene pools. Given escalating challenges such as climate change, land degradation, and emerging pests and diseases,

CWRs are gaining increasing attention. However, despite their recognized value, these resources remain under-collected, under-conserved, and under-utilized in breeding programs.

Historically, CWRs have played pivotal roles in crop improvement through wide hybridization. Notable examples include the “nobilization” of sugarcane in India by crossing *Saccharum officinarum* with *S. spontaneum* to produce high-yielding and stress-tolerant varieties like Co 205. Similar successes include the incorporation of useful genes for stress tolerance and quality enhancement. Advances in genomics and molecular breeding now accelerate the identification and transfer of useful genes from wild relatives to cultivated crops, bolstering efforts toward climate-resilient and sustainable agriculture (Bohra *et al.*, 2021).



Fig.1. Representative Image of few CWRs

Importance of Crop Wild Relatives

- **Reservoirs of Genetic Diversity:** CWRs harbor extensive genetic variability that has been lost or never existed in cultivated crops. Traits such as drought tolerance, salinity resistance, cold and heat tolerance, pest and disease resistance, and adaptability to marginal environments are often abundant in wild relatives due to natural selection under diverse and harsh conditions. This genetic diversity forms the raw material for crop improvement and long-term agricultural sustainability.
- **Contribution to Food and Nutritional Security:** Historically, CWRs have made significant contributions to global food security. Genes from wild relatives have been successfully incorporated into crops such as rice, wheat, maize, potato, sugarcane, tomato, and many legumes. For example, resistance to grassy stunt virus in rice was obtained from *Oryza nivara*, late blight resistance in potato from *Solanum demissum*, and stem rust resistance in wheat from *Aegilops* species. These contributions have resulted in enhanced yield stability and reduced dependence on chemical inputs.

- **Climate Change Adaptation:** Climate change poses unprecedented challenges to agriculture, including increased frequency of droughts, floods, heat waves, and salinity intrusion. Many CWRs thrive in extreme environments and possess adaptive traits that can be harnessed to develop climate-resilient crop varieties. The utilization of CWRs is therefore critical for climate-smart agriculture and sustainable crop production systems.
- **Evolutionary and Ecological Significance:** CWR provide insights into the evolutionary history of crops and the processes of domestication. They also play vital roles in natural ecosystems, contributing to ecological balance and resilience. The loss of CWR would not only undermine crop improvement efforts but also weaken ecosystem services.

Conservation of Crop Wild Relatives

CWRs are increasingly threatened by habitat destruction, agricultural expansion, urbanization, deforestation, overgrazing, invasive species, and climate change. Many CWRs occur in disturbed habitats such as field margins, forest edges, and roadsides, which are rarely protected. As a result, several CWR taxa are now rare, endemic, or threatened with extinction. Different conservation strategies are employed for CWRs. *In situ* conservation involves the protection and management of CWRs within their natural habitats. This approach allows continued evolution and adaptation of species under natural selection pressures. Protected areas, biosphere reserves, can serve as important sites for *in situ* conservation. However, many CWR-rich habitats lie outside protected areas, necessitating innovative conservation approaches such as on-farm conservation and conservation in agricultural landscapes. *Ex situ* conservation refers to the preservation of genetic resources outside their natural habitats, primarily in seed genebanks, field genebanks, *in vitro* collections, and cryopreservation facilities. Seed genebanks are the most cost-effective method for conserving CWRs with orthodox seed behavior. However, many CWRs, particularly tree species and tropical crops, produce recalcitrant seeds and require alternative conservation strategies. An integrated approach combining *in situ* and *ex situ* methods often referred to as “complementary” or “trans situ” conservation is increasingly recognized as the most effective strategy for CWRs conservation (Riordan *et al.*, 2019). This approach enhances genetic representation, buffers against risks, and facilitates sustainable utilization.

Utilization of Crop Wild Relatives in Crop Improvement

Despite their immense potential for crop improvement and adaptation to changing environments, the successful utilization of crop wild relatives (CWRs) has been achieved in only

a few major crops (Hajjar *et al.*, 2007). Numerous valuable genes within these wild resources remain untapped, largely due to limited genetic information and existing bottlenecks. Breeders often focus on identifying genes linked to specific desirable traits in known CWRs rather than exploring their genetic diversity more broadly. They also tend to prefer using pre-breeding lines that incorporate beneficial wild traits into cultivated genetic backgrounds. So far, major efforts have focused on crops like wheat, rice, barley, tomato, soybean, and mustard. However, the use of CWRs remains far below its potential, hindered by cross-incompatibility barriers, hybrid infertility, poor conservation and availability of wild germplasm, insufficient evaluation data, and challenges in expressing wild traits in cultivated backgrounds. Moreover, limited accessibility of CWR materials to researchers and breeders further restricts their effective use in crop improvement programs.

Table 1. List of few crop wild relatives with their important traits

Crop	Taxa	Desirable traits
Barley	<i>Hordeum spontaneum</i>	Resistant to <i>Helminthosporium</i> , powdery mildew, net type net blotch, <i>Septoria</i> speckled leaf-blotch, leaf-scald and is tolerant to drought and cold
	<i>Hordeum bogdanii</i>	Resistant to aphids
	<i>Hordeum marinum</i> subsp. <i>gussoneanum</i>	Tolerance to salinity and waterlogging
	<i>Hordeum murinum</i> subsp. <i>glaucum</i>	Resistant to leaf-scald
Rice	<i>Oryza rufipogon</i>	Resistant to sheathblight, bacterial leaf blight (BLB), blast, <i>Rice tungro virus</i> (RTBV/RTSV) and brown planthopper (BPH) and stripedborer
	<i>Oryza nivara</i>	Resistant to <i>Rice grassy stunt virus</i> (RGSV), blast and drought avoidance
	<i>Oryza officinalis</i>	Resistant to BPH, green leafhopper (GLH), white-backed plant hopper (WBPH), zigzag leafhopper, BLB, yellow stem borer,

		stripedborer and RTBV/RTSV
	<i>Oryza malampuzhaensis</i>	Multiple pest resistance
	<i>Oryz meyeriana</i> var. <i>granulata</i>	Photoperiod insensitive; grains have good aroma; is resistant to yellow stem borer, BLB, BPH, and gall midge
	<i>Oryza coarctata</i>	Salt tolerance; immune to yellow stem borer and is resistant to gall midge
Wheat	<i>Aegilops tauschii</i>	Resistance to leaf-rust, stem-rust, stripe-rust, powdery mildew, cyst-nematode, hessian-fly, greenbug
	<i>Elymus dahuricus</i>	Salinity and drought tolerant
	<i>Elymus nutans</i>	Tolerant to cold, drought and resistant to pests
	<i>Elymus repens</i>	Resistance to <i>Fusarium</i> head- blight
	<i>Leymus secalinus</i>	Drought and salinity tolerant
Pigeon pea	<i>Cajanus scarabaeoides</i>	Resistant/tolerant to pod-borer, bruchid, pod-wasp, drought
	<i>Cajanus sericeus</i>	Resistant to <i>Pigeonpea sterility mosaic virus</i> , <i>Phytophthora</i> blight, pod-borer, and pod-fly and tolerant to drought and salinity
	<i>Cajanus albicans</i>	Resistant to <i>Pigeonpea sterility mosaic virus</i> , pod-fly, <i>Phytophthora</i> blight, pod-wasp, tolerant to soil salinity and drought.
	<i>Cajanus lineatus</i>	Resistant to <i>Pigeonpea sterility mosaic virus</i> , <i>Phytophthora</i> blight, pod-borer and pod-fly, tolerant to salinity and drought
Chickpea	<i>Cicer microphyllum</i>	Tolerant to drought, cold, <i>Pea streak virus</i> , and <i>Helicoverpa</i> pod-borer
Black gram	<i>Vigna silvestris</i>	Tolerant to <i>Mungbean yellow mosaic virus</i> (MYMV), resistant to bruchids
Greengram	<i>Vigna sublobata</i>	Resistant to bruchids, <i>yellow mosaic virus</i> ;

		tolerant to drought, saline, and alkaline soils
	<i>Vigna subramaniana</i>	Resistant to bruchids
Mustard	<i>Brassica tournefortii</i>	Resistant to the mustard aphid, <i>Alternaria</i> blight, white rust and tolerant to drought, shattering
Linseed	<i>Linum perenne</i>	Tolerant to drought and cold
Sesame	<i>Sesamum prostratum</i>	Tolerant to drought and salinity, resistant to phyllody, powdery mildew
	<i>Sesamum laciniatum</i>	Resistant to phyllody, leaf webber, tolerant to drought
	<i>Sesamum alatum</i>	Resistant to phyllody
	<i>Sesamum radiatum</i>	Has a high number of capsules and wide adaptation; tolerant to drought, resistant to powdery mildew, leaf-webber, and phyllody
Cotton	<i>Gossypium stocksii</i>	Resistant to pink bollworm
Okra	<i>Abelmoschus tuberculatus</i> var. <i>tuberculatus</i>	Resistant to shoot-borer and tolerant to <i>Bhendi yellow vein mosaic virus</i>
	<i>Abelmoschus ficulneus</i>	Resistant to <i>Okra enation leaf curl virus</i> , <i>Cercospora</i> , and <i>Alternaria</i> .
	<i>Abelmoschus pungens</i> var. <i>pungens</i>	Resistant to <i>Bhendi yellow vein mosaic virus</i> , powdery mildew, and fruit borer
	<i>Abelmoschus pungens</i> var. <i>mizoramensis</i>	Resistant to <i>Bhendi yellow vein mosaic virus</i>
	<i>Abelmoschus tetraphyllus</i>	Resistant to <i>Bhendi yellow vein mosaic virus</i>
Onion	<i>Allium roylei</i>	Resistant to downy mildew, leaf blight, anthracnose, and powdery mildew
Brinjal	<i>Solanum lasiocarpum</i>	Resistant to fruit-borer
	<i>Solanum viarum</i>	Frost tolerance, tolerant to littleleaf
	<i>Solanum virginianum</i>	Resistant to fruit-borer, bacterial-wilt, and <i>Phomopsis</i>

Future Perspectives and Strategies

To unlock the full potential of crop wild relatives, the following actions are critical:

- Prioritizing CWRs based on economic importance, conservation status, and breeding relevance.
- Developing comprehensive national and regional inventories and gap analyses.
- Conducting targeted exploration and germplasm collection.
- Strengthening evaluation, pre-breeding, and characterization programs.
- Integrating genomics and phenomics to accelerate gene identification and transfer.
- Enhancing policy frameworks and international cooperation on access and benefit-sharing.

Conclusion

Crop wild relatives constitute a vital but underutilized resource for crop improvement and agricultural sustainability. Their conservation and effective utilization are imperative in the face of genetic erosion, climate change, and rising global food demand. A strategic, integrated approach that links conservation with utilization, supported by modern scientific tools and strong institutional frameworks, is essential to harness the full potential of CWRs. Ensuring their conservation and utilisation today will determine the resilience, productivity and sustainability of crops tomorrow.

Reference

- Bohra, A., Kilian, B., Sivasankar, S., Caccamo, M., Mba, C., McCouch, S. R., et al. (2021). Reap the crop wild relatives for breeding future crops. *Trends Biotechnol.* 40, 412–431. doi: 10.1016/j.tibtech.2021.08.009
- Hajjar, R., & Hodgkin, T. (2007). The use of wild relatives in crop improvement: a survey of developments over the last 20 years. *Euphytica*, 156(1), 1-13.
- Maxted, N., Ford-Lloyd, B. V., Jury, S., Kell, S., & Scholten, M. (2006). Towards a definition of a crop wild relative. *Biodiversity & Conservation*, 15(8), 2673-2685.
- Riordan, E. C., & Nabhan, G. P. (2019). Trans situ conservation of crop wild relatives. *Crop Science*, 59(6), 2387-2403.

CANOPY SHYNESS ITS CAUSES AND EVOLUTIONARY SIGNIFICANCES

Article ID: AG-VO5-I12-121

Dr. M. Shanmuganthan*

Professor (PBG), Department of Genetics and Plant Breeding

Agricultural College and Research Institute, Kudumiyamalai – 622 104, Tamil Nadu, India

*Corresponding Author Email ID: shanmuganathan.m@tnau.ac.in

Introduction

Canopy shyness (also known as **crown shyness**) is a natural phenomenon where the uppermost branches and leaves of fully grown trees avoid touching each other, creating visible gaps in the forest canopy. These gaps form intricate, puzzle-like patterns when viewed from below, almost like the trees are socially distancing and the phenomenon is more pronounced among trees of the same species but can also occur between different species. Crown shyness is thought to arise from factors such as competition for light and resources, physical abrasion between branches in the wind and possibly as a defense mechanism to reduce the spread of pests and diseases between trees. This behavior varies among species and environmental conditions and can be influenced by tree density, branch flexibility and seasonal changes.

Common Trees That Exhibit canopy shyness

- *Dryobalanops aromatica* (in Southeast Asia)
- Certain eucalyptus species
- Black mangrove
- Japanese cedar
- Pine
- Oak
- Dipterocarps

Where to See It

- Canopy shyness is best viewed in dense forests, often tropical or subtropical.

- It's especially striking when looking directly up at the canopy from the forest floor.

Crown shyness occurs in various forest types globally:

- Tropical dipterocarp forests in Malaysia and Indonesia.
- Eucalyptus forests in Queensland, Australia.
- Pine forests in Florida, USA.
- Cloud forests in Costa Rica.
- Temperate forests in Japan.

Causes of Canopy Shyness

The causes of canopy shyness are still being studied, but several leading theories attempt to explain why the upper branches of trees avoid touching each other, creating visible gaps. Here's a breakdown of the main causes:

1. Mechanical abrasion (wind damage theory)

- Explanation: As trees sway in the wind, branches may collide and damage each other.
- Result: Over time, trees may limit their growth toward neighboring trees to prevent repeated physical damage.
- Evidence: In experiments, trees grown in windless environments or with padded branches sometimes show reduced or no canopy shyness.

2. Light optimization (photoreceptor theory)

- Explanation: Trees might detect nearby foliage through changes in light quality (like red:far-red light ratios) and adjust their growth to maximize their own light intake.
- Result: Gaps form to optimize photosynthesis without overcrowding or shading neighbors too much.
- Note: This mechanism involves plant photoreceptors like phytochromes.

3. Pest and disease avoidance

- Explanation: Physical contact between trees can act as a bridge for insects, fungi, or diseases to spread.
- Result: Avoiding contact could be an evolutionary adaptation to reduce pathogen transmission.

4. Genetic programming or intra-specific regulation

- Explanation: Some species exhibit crown shyness more than others, suggesting a genetic or species-specific trait.

- Result: Tree species with this trait naturally limit crown expansion near neighbors of the same or different species.

5. Self-pruning and growth inhibition

- Explanation: When tree branches sense nearby competition (mechanically or via light), they may inhibit cell elongation or growth in that direction.
- Result: Branches "pull back" before they meet, maintaining clear spaces.

Evolutionary significances of canopy shyness

Canopy shyness is thought to offer several evolutionary significances to plants and trees, especially in dense forest environments. While the exact cause is still debated, the benefits of canopy shyness - intentional or incidental - can be quite significant for individual trees and the forest ecosystem as a whole.

1. Survival advantage: reducing physical damage

- Benefit: Prevents branches and leaves from colliding during wind or storms.
- Why it matters: Constant rubbing or collision can cause wounds, broken branches, or leaf loss, which weakens the tree.
- Result: Conserves energy by avoiding the need to repair damaged tissues.

2. Efficient resource allocation (light & energy)

- Benefit: Allows more uniform distribution of sunlight through the canopy.
- Why it matters: Reduces shading of lower branches or neighboring plants (self-shading).
- Result: Enhances photosynthetic efficiency which supports **stronger growth and better seed production**, enhancing reproductive success.

.3. Reduces spread of pests and diseases

- Benefit: Limits direct contact between leaves and branches of neighboring trees.
- Why it matters: Many pests and pathogens spread through direct contact. Avoiding direct contact with other trees may **reduce the spread of insects, fungi and diseases** that move across branches or leaves.
- Result: Creates a form of natural quarantine, especially useful in dense forests.

4. Encourages healthy growth patterns

- Benefit: Promotes spatial awareness in trees, reducing unnecessary competition.
- Why it matters: Instead of competing aggressively for space, trees regulate their growth to avoid wasting energy.

- Result: Promotes more sustainable and cooperative growth among trees.

5. Supports biodiversity

- Benefit: Canopy gaps allow filtered sunlight to reach the forest floor.
- Why it matters: Supports the growth of understory plants, mosses and small shrubs.
- Result: Enhances plant and insect biodiversity by creating microhabitats.

6. Species-specific adaptation

- **How it helps:**
 - Some tree species show crown shyness while others don't.
 - This suggests it may be a **selective trait** that evolved in certain lineages due to specific environmental pressures (e.g., wind-prone or high-density forests).
- **Evolutionary benefit:** These traits may be **naturally selected** where they increase fitness in a given environment.

7. Promotes coexistence and forest stability

- **How it helps:**
 - By creating **equidistant spacing** between crowns, crown shyness can reduce aggressive competition for space.
 - This spatial regulation may promote **species coexistence** in biodiverse forests.
- **Evolutionary benefit:** Trees that don't overcompete may **co-survive** with others, maintaining **long-term ecosystem stability**, which is beneficial for all species over time.
- The unique canopy gaps act as microhabitats, fostering species with differing habitat preferences, thus increasing both plant and animal species diversity within the forest.

8. Effect on seedling survival

- With improved light and microclimate conditions, crown shyness contributes to higher rates of seedling survival, especially in early life stages that are highly vulnerable to competition, shading and resource scarcity.
- However, seedling survival rates remain variable and can be influenced by other factors such as soil conditions, predation and specific plant adaptations, but overall, crown shyness increases the number of suitable establishment sites.

9. Increase nutrient cycling

- Crown shyness also influences nutrient cycling by affecting conditions such as moisture and temperature at ground level, which can impact decomposition rates and soil fertility,

- further contributing to the overall resilience and biodiversity of the forest ecosystem.

The **evolutionary significance of crown shyness** lies in how it may help trees **survive, reproduce and compete** more effectively in dense forest environments over generations. While not all scientists agree on whether it is an **adaptive trait** or a byproduct of other processes, there is growing evidence that crown shyness **offers evolutionary advantages**.

Is it an evolved trait or a byproduct?

Some scientists suggest crown shyness may **not be directly selected** for but could be a **byproduct** of:

- Mechanical abrasion
- Hormonal growth regulation
- Light sensing mechanisms

Still, because these effects **confer survival and fitness benefits**, they may be **reinforced by natural selection** over time.

Conclusion

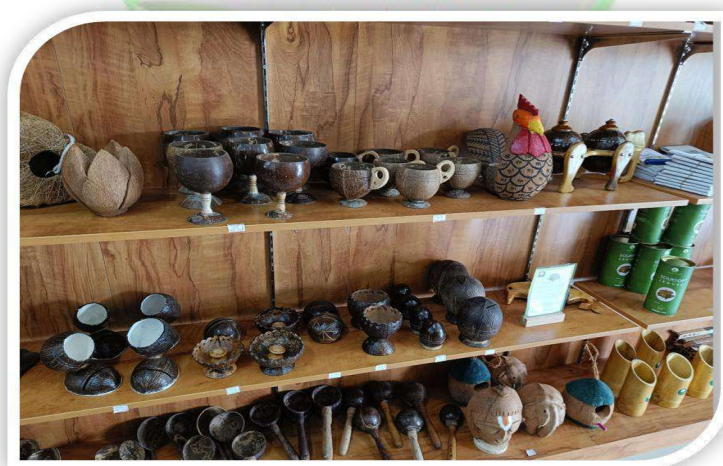
Crown shyness is a fascinating natural adaptation where tree crowns maintain a respectful distance, creating visually captivating canopy patterns while optimizing resource use and potentially reducing damage and disease transmission. Increased light and the diverse microclimates created by crown shyness allow a richer variety of understory plants to thrive, which in turn attracts and supports more animal species, such as insects, birds and small mammals. It also facilitates seedling establishment and survival by optimizing light distribution and creating varied microenvironments on the forest floor, fostering diverse and resilient young plant populations in forest ecosystems.

IS “ECO-FRIENDLY” REALLY ENVIRONMENTALLY FRIENDLY?

Article ID: AG-VO5-I12-122**¹Janani N and ²Lakshmana Raj P***¹Editor-in-Chief - Eco Calls; ²Founder - Eco Calls*Corresponding Author Email ID: eco2calls@gmail.com

Introduction

When a product is designed to have little or no negative impact on the environment—or when actions conserve natural resources and reduce pollution throughout their life cycle, thereby promoting the Earth’s long-term health—it is often called eco-friendly. On the other hand, environmentally friendly refers to practices, products, or behaviours that cause minimal or no harm to the environment. These are designed to reduce pollution, conserve resources, and support sustainability throughout their entire life cycle—from sourcing and production to usage and final disposal—aiming to minimize negative impacts on ecosystems.



At first glance, these two terms may appear similar, but they are not identical. Eco-friendly generally highlights specific green features such as biodegradable packaging, recycled materials, organic raw materials, or energy-efficient design. Environmentally friendly, however, takes a

broader perspective, focusing on overall impact. It applies not only to products, but also to processes, policies, and behaviours, such as choosing public transportation, reducing energy consumption, avoiding single-use products, and conserving water.

ARE OUR DAILY PRODUCTS TRULY ENVIRONMENTALLY FRIENDLY?

From the moment we wake up until we go to sleep, how many of the products we use are truly environmentally friendly? Do we consider how many times we use a product in our lifetime? What happens after consumption? How much waste do we generate? Are we aware of how these products are manufactured? And beyond humans, how many other living organisms are affected by our actions?

If we honestly answered all these questions, we might conclude that avoiding all products is impossible—unless we choose to live like primitive humans. In modern lifestyles, such an option is unrealistic. Therefore, the practical path forward lies in eco-friendly choices, environmentally responsible practices, and sustainability.

CAUSES AND EVOLUTION OF ECO-FRIENDLY CONSUMPTION

Identifying truly eco-friendly products is challenging. In Western societies, green consumption began gaining attention during the 1960s and early 1970s, driven by increasing awareness of environmental protection. This movement gained momentum following highly publicized ecological disasters such as oil spills and nuclear incidents, as well as influential publications like Rachel Carson's "Silent Spring", which exposed the harmful effects of pollutants.

Furthermore, international environmental summits played a crucial role in establishing legal frameworks and raising global awareness. Key milestones include the Stockholm Conference (1972), the Rio Earth Summit (1992), and the Paris Agreement (2015), all of which significantly influenced global action on climate change, biodiversity loss, and pollution.

PRIORITIZATION MATTERS

A major shift has occurred from prioritizing the "value of money" to recognizing the "value of life." This change reflects evolving consumer behaviour driven by concerns for sustainability, health, and ethics. Although price sensitivity still exists, studies show that around 74% of consumers consider environmental impact in their purchasing decisions. Environmental health is increasingly linked to personal well-being. The availability of information through the internet and social media has empowered consumers to make informed choices. Younger

generations—particularly Millennials and Gen Z—are leading this shift, with higher income and education levels further supporting sustainable consumption. However, doubts about product effectiveness, high costs, or limited availability often hinder adoption. A product's success depends on research, design, production, packaging, marketing, and accessibility. If any one of these elements fails, the sustainability cycle weakens.

IS ECO-FRIENDLY THE SAME AS BIODEGRADABLE?

The term eco-friendly is broad and does not mean biodegradable by default. It may refer to reduced carbon footprint, recyclability, non-toxicity, or compostability. Many eco-friendly products combine both biodegradable and non-biodegradable components. For example, stainless steel, glassware, and synthetic fibres are preferred for their durability and long life, reducing frequent replacement. While eco-friendly in intent, they pose disposal challenges and may persist in landfills for centuries if not recycled properly. Recycling reduces the need for new resources, but recycled materials—especially plastics and metals—eventually become waste. This highlights the importance of a circular economy, where reuse and responsible disposal are prioritized. Comparatively, eco-friendly products still have a lower environmental impact than conventional alternatives. No product is manufactured with zero emissions. However, emissions can be significantly reduced through energy-efficient production, minimal water usage, and local sourcing. The Earth does not belong only to humans—it is home to all living organisms.

ROLE OF WASTE MANAGEMENT IN ENVIRONMENTAL PROTECTION

As the global population continues to grow, waste generation has reached unprecedented levels. Effective waste management plays a crucial role in environmental protection, pollution reduction, resource conservation, and economic development. Proper waste handling protects ecosystems, wildlife, and human health by diverting waste from landfills and reducing contamination risks, ultimately leading to a cleaner and more sustainable planet.

THE 'R's OF WASTE MANAGEMENT

- ❖ Refuse – Decline unnecessary items such as single-use plastics, freebies, and excessive packaging.
- ❖ Reduce – Minimize consumption by buying less and choosing durable products.
- ❖ Reuse – Extend product life through repair and repeated use.
- ❖ Repurpose – Creatively transform waste into new, useful products.
- ❖ Recycle – Convert waste into new materials, only after exhausting other options.

- ❖ Rot – Compost organic waste like food scraps to enrich soil.

Who knows—perhaps even coloured dustbins can influence environmental behaviour? The right path leads to the right destination. By acting responsibly today, we present a healthier environment to future generations.

“ECO-FRIENDLY SHOWS THE WAY: WE MUST JOIN TO DRIVE POLLUTION AWAY.”

REFERENCES

1. Carson, R. (1962). Silent Spring. Houghton Mifflin, Boston.

- A foundational work highlighting the environmental impacts of pollutants.

2. United Nations Environment Programme (UNEP). (2011).

- Explains sustainability, eco-friendly practices, and environmental impact.

3. European Commission. (2020), Circular Economy Action Plan.

- Discusses waste reduction, recycling, reuse, and circular economy concepts.

4. United States Environmental Protection Agency (EPA), Reduce, Reuse, Recycle.

- Source for waste management principles and the “R” hierarchy.

Volume: 05 Issue No: 12

HORTICULTURAL HERITAGE OF INDIA: INSIGHTS INTO GEOGRAPHICAL INDICATIONS

Article ID: AG-VO5-I12-123**Gowthami R^{1*}, Subhash Chander², Pranusha P^{1*}, Parameswari B¹, and Saravanan L¹**¹ICAR-National Bureau of Plant Genetic Resources, Regional Station, Hyderabad-500030²ICAR- National Bureau of Plant Genetic Resources, New Delhi-110012, India

*Corresponding Author Email ID: gowthamir111@gmail.com

Abstract

Geographical Indications (GIs) in Indian horticulture safeguard products tied to specific regions, reflecting the unique influence of local soil, climate, and traditional practices. India currently has many registered GIs, with horticultural commodities such as fruits, vegetables, spices, flowers, and plantation crops. GIs help to improve market access, strengthen premium branding, protect biodiversity, and preserve indigenous knowledge systems. They promote the on-farm conservation of traditional varieties while supporting sustainable agricultural practices and enhancing the livelihoods of rural communities.

Introduction

Geographical Indications (GIs) identify products originating from specific regions, deriving unique qualities from local factors like soil, climate, and traditions. In India, public agencies like the Geographical Indications Registry under the Department for Promotion of Industry and Internal Trade enforce protections via the Geographical Indications of Goods (Registration and Protection) Act, 1999. This safeguards rural products, boosting market value and cultural heritage. The efforts of public and quasi-public agencies to provide legal protection for Indian Geographical Indications represent an important step in safeguarding and leveraging the market potential of reputable origin-linked products. In view of the fact that most GIs are associated with rural culture, climate, and community life, there is considerable scope to strengthen the brand image of these distinctive products by highlighting their cultural attributes. Most registered GI products successfully tap into this market potential, thereby benefiting

producers (Singh et al. 2024). The significance of GIs is illustrated in Fig. 1.

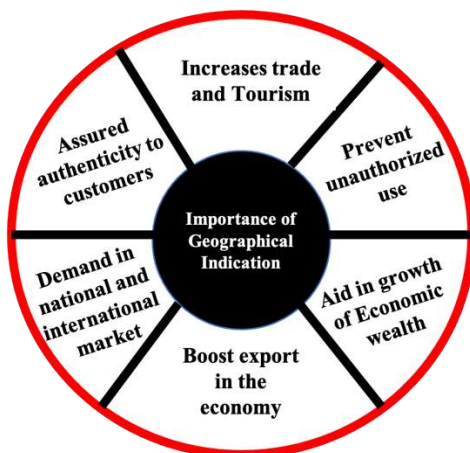


Figure 1. Significance of Geographical Indication

Legal Protection Efforts

Public and quasi-public bodies, including state governments and agricultural institutes, promote GI registration to prevent misuse and enhance economic prospects for origin-linked goods. As of 2025, India has > 600 registered GIs, with efforts focusing on documentation, branding, and legal enforcement to capitalize on global demand (IPINDIA.GOV.IN). These initiatives integrate with schemes like One District One Product (ODOP) for rural empowerment. Horticulture dominates agricultural GIs at around 76-84%, led by fruits (46.6% or 61 registrations), followed by vegetables (14% or 25), plantation/spices (15.1% each), flowers (5.8% or 6), and aromatics (3.5%). Maharashtra and Karnataka lead in horticultural GI ownership, enhancing rural economies through premium branding.

Diversity of GI-Tagged Horticultural Crops in India

Several prominent Indian horticultural products (fruits, vegetables, plantation crops, spices, flowers, nuts) have GI registration, with fruits and plantation/spice crops dominating, and vegetables and flowers forming a smaller but growing group. Below are illustrative examples.

• **Fruit crops:** Alphonso Mango (Maharashtra) and Appemidi Mango, Nanjangud Banana, Kamalapur Red Banana, Coorg Orange (Karnataka). Devanahalli Pomello, Bangalore Blue Grapes, Bangalore Rose Onion (though an onion, often cited with fruit GIs in Karnataka lists). Mahabaleshwar Strawberry, Nashik Grapes, Jalgaon Banana, Dahanu Gholvad Chikoo, Beed Custard Apple, Jalna Sweet Orange, Purandar Fig, Solapur Pomegranate (Maharashtra). Allahabad Surkha Guava, Malihabadi Dussehri Mango (Uttar Pradesh); Laxman Bhog,

Himsagar, Fazli mangoes (West Bengal)

• **Vegetable crops:** Bydagi Chilli (Karnataka), Guntur Sannam Chilli (Andhra Pradesh), Bhawani / Bhiwapur-type chillies and other regional chillies. Udupi Mattu Gulla Brinjal (Karnataka); Jalgaon Bharit Brinjal (Maharashtra). Bangalore Rose Onion (Karnataka); Lasalgaon Onion (Maharashtra). A French bean type and other localized vegetable landraces together make 13 registered vegetable GIs up to 2020, with chilli (6), tomato (1), brinjal (2), onion (2), garlic (1), French bean (1).

• **Plantation crops and beverages:** Darjeeling Tea (word and logo) from West Bengal, the first Indian GI in agriculture. Kangra Tea (Himachal Pradesh); Nilgiri Teas from Tamil Nadu (various registrations). Coorg Arabica Coffee, Chikmagalur Arabica Coffee, Bababudangiri Arabica Coffee, Malabar Arabica Coffee, Monsooned Malabar Robusta Coffee (mainly Karnataka/Kerala). Coorg Green Cardamom, Eathomozhy Tall Coconut, Sirsi Supari (arecanut) and other plantation nuts/palms.

• **Spices and condiments:** Multiple chilli GIs (e.g., Bydagi, Khola, Guntur Sannam) with distinct pungency and colour profiles. Turmeric types such as Waigaon Turmeric (Maharashtra) and Kandhamal Haldi (Odisha). Ginger and Tejpat (Indian bay leaf) GIs noted among spice and M&A crops.

• **Flowers and aromatic crops:** Mysore Mallige, Udupi Mallige, Hadagali Mallige jasmines (Karnataka). Jasmine and Kewda (ketaki) recognized among horticultural GIs, mainly for fragrance and traditional uses.

Advantages of Geographical Indications in Indian Horticulture System

- **Protecting Biodiversity and Community Knowledge Systems:** Geographical Indications (GIs) play a vital role in protecting plant biodiversity and preserving the traditional knowledge of local, community, and tribal groups involved in the production of handicrafts, natural goods, artifacts, and manufactured products (Lalitha and Vinayan, 2018). By recognizing and safeguarding origin-linked products, GIs promote time-tested production practices that are closely associated with sustainable natural resource management and the maintenance of species within their natural ecosystems.
- **Production, quality and branding:** Codified GI production protocols promote standardized cultivation, harvest and post-harvest handling, helping maintain consistent quality, flavour, colour and shelf life in horticultural commodities. GI logos on packages of fresh and

processed produce support traceability and premium pricing in domestic and export markets, strengthening brand identity for orchards and grower cooperatives.

- **Market access and export promotion:** Geographical Indications (GIs) offer an effective platform for securing premium market prices and generating higher demand by branding products with assured quality, authenticity, and origin. GI recognition enhances consumer willingness to pay premium prices and improves market acceptance of Indian horticultural products in high-value international markets. This strengthened market visibility increases revenues for local producers and small-scale entrepreneurs while enabling niche marketing of GI-tagged fruits, vegetables, flowers, and spices. Such opportunities also support agri-tourism, specialty retail, and e-commerce. GI horticulture supports small and marginal farmers through collective branding, organized marketing and better bargaining power, improving rural incomes.
- **Public sensitization and education:** Maintaining and promoting GI status often requires raising public awareness about the product's significance and its connection to the local ecosystem. Educational initiatives linked to GIs can inform consumers and communities about conservation efforts, including the protection of endangered species and the role of sustainable practices in ensuring their survival. Such awareness supports conservation objectives while strengthening appreciation for GI-linked products.

Conservation of GI-Tagged Horticultural Germplasm in India

GI crops strongly promote *in situ* conservation by ensuring the continued cultivation and management of traditional, region-specific varieties within their original agro-ecological settings. Because GI protection is fundamentally tied to geographical origin, soil characteristics, climate, and customary production practices, farmers and producer groups are encouraged to safeguard these crops on-farm in order to retain their legally protected identity and quality attributes. Continued cultivation not only safeguards the distinctive genetic makeup, sensory attributes, and adaptive capacities that characterize GI varieties but also allows evolutionary processes to operate naturally under local environmental pressures, sustaining their dynamic adaptation and resilience. However, while *in situ* approaches are essential for maintaining the ecological and cultural integrity of GI crops, research on complementary *ex situ* conservation strategies is equally critical. Natural disasters, climate variability, pest outbreaks, or changes in land-use patterns pose significant risks to the persistence of traditional landraces in their original habitats.

Establishing systematic *ex situ* conservation frameworks, including seed banks, field gene banks, cryopreservation, and *in vitro* repositories, would ensure the long-term preservation of genetic material associated with GI crops.

Challenges and Future Prospects

Key challenges include species-specific protocol optimization, cost and skill requirements. Promoting research is essential to identify effective strategies and tools for using Geographical Indications in the conservation of biodiversity, while simultaneously advancing scientific knowledge and practical applications. Collaborative trials enhance utilization for sustainable agro-biodiversity.

References

1. Singh, G., Sharma, K., Dower, S., Rana, S., Soni, R., Singh, V. K., & Sinha, R. P. (2024). Horticultural geographical indications of India: botanical aspect. *Vegetos*, 37(3), 803-817.
2. IPINDIA.GOV.IN;https://ipindia.gov.in/writereaddata/Portal/Images/pdf/State_wise_Registered_GI_of_India_26_07_2024.pdf
3. Lalitha, N., & Vinayan, S. (2018). GIs for Protecting Agrobiodiversity and Promoting Rural Livelihoods: Status, Strategies and Way Forward. *Journal of Rural Development*, 479-500.

RAIN WATER HARVESTING: USING EVERY DROP WISELY

Article ID: AG-VO5-I12-124**Dr. Rajeshwari Desai* and Tejaswini K Machenahalli****

* Senior Scientist, AICRP-WIA, University of Agricultural Sciences, Dharwad-5,
Karnataka, India

** MSc Scholar, University of Agricultural Sciences, Dharwad-5, Karnataka

*Corresponding Author Email ID: rajeshwarimd@uasd.in

Introduction

The Earth's surface is covered by vast water resources(75% surface of the earth); however, access to water is a major problem for many people. It is estimated that 2.2 billion of the global population is still struggling with access to safe water which is a necessity for human existence (UNICEF 2019). The situation is in arid and semi-arid regions of the world

due to climate conditions, uneven rainfall, and excessive rise in temperature, leading to water scarcity and drought which affect food security and livelihoods of people.

Water is life. Without water, the existence of life on Earth is unimaginable. A human being may survive for nearly three weeks without food, but cannot endure even three days without water. Therefore, we must value and conserve water, even if it seems abundant or comes at no cost. Every drop is precious, and its careful use today ensures life and sustainability for tomorrow.

The sources of water include surface water and ground water. Surface water includes lakes, ponds, rivers, oceans etc. which is being polluted by industrialization and urbanization, making it unfit for human use. And the groundwater is being used in excess due to population growth.



The one age old solution to combat the scarcity of water is **rain water harvesting**. It is the process of collecting the rain water from surface like roof top and storing for the future use, rather than letting runoff the rain water. This is a very ecofriendly, affordable and a effective method of water conservation method. This method is beneficial for both human and to the environment.

The importance of rainwater harvesting lies in the fact that it can be stored for future use. Just as it can be used directly so also the stored water can be utilized to revitalize the ground level water and improve its quality. Harvesting rainwater checks surface run off of water and reduces soil erosion.

Rain water harvesting is a very simple process it involves:

- i. Making provision for a roof that is as clean as possible, so that we can collect the rain water.
- ii. Draw rainwater down through pipes or gutters as necessary.
- iii. Separate a little amount of water from the first rain because it contains leaves and dust and filter the rest.
- iv. Store the harvested water in sump tank or lined pond for later use or charge the groundwater through percolation pits, open wells or bore wells.

The water conserved through the rain water harvesting can be used for the domestic use. Indoor use include using for bathing, washing clothes, utensils, toilet flushing, cleaning. Outdoor use include using the rain water for gardening, washing vehicles, providing drinking water for livestock, and for washing life stocks. Using the rainwater will significantly leads to reduce in the water bill by reducing the dependence on corporation water. It reduces the dependence on the groundwater and replenish the groundwater recharge. In the agriculture field this technique has a very important role it help in reducing the soil erosion, provides the reliable water resources, and during the drought it provides the stored water.

There are various ways by which rain water is harvested in India.

1)Storage of Rain water from the rooftop it is a very simple and used since long. Channeling rainwater made from rooftop to storage tanks. The water can be used for daily life activities.



2) Recharging Groundwater Aquifers in which Communities in places like Rajasthan use techniques like check dams, ponds, and groundwater recharge wells to trap rainwater and let it percolate into the ground. This helps replenish groundwater levels naturally, creating a sustainable water source for the future.

3) Stepwells which are designed to hold the rain water. System where steps lead down to a water source, like a well or tank, designed to cleverly conserve every drop of rainwater. These steps minimize evaporation by reducing the water's surface area, while providing a pathway to the water table - a lifeline in dry regions with **limited rainfall**. As the rain pours down, it's channeled into these ingenious structures, where it slowly seeps into the ground, recharging aquifers and ensuring a steady supply of water.

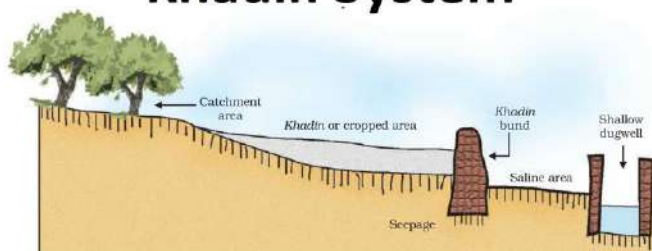


4) Khadin system Primarily used in Rajasthan, where a long earthen embankment is built across a valley to trap surface runoff for agriculture. This stored water saturates the land, increasing soil moisture for crops grown during the subsequent dry season and also recharging groundwater.

Error!Error!Error!



Khadin System



5) Jhalaras are the man-made tanks which serves as the ground water recharge system.



By recognizing the increasing water scarcity due to urbanization and industrialization and no proper management of water, government has taken number of steps to promote rain water harvesting through policies, awareness campaign, and some strict mandates to be followed. And the programs or schemes undertaken by government include:

“Jal Shakti Abhiyan: Catch the Rain” (JSA:CTR) with the theme “Catch the Rain Where it Falls When it Falls”, launched in 2021 to coincide with the pre-monsoon and monsoon seasons. This initiative has helped revive thousands of water bodies and improve groundwater recharge, especially in drought-prone areas, aiming to build a water-secure future for India. Major works include:

❖ **Water Conservation and Rainwater Harvesting Structures**

Building new structures: Creation of check dams, gabion structures, water harvesting pits, and installing rooftop rainwater harvesting systems on government and other buildings.

Renovating existing structures: Repairing traditional step-wells, desilting tanks to increase storage capacity, and removing obstructions from channels.

Rejuvenating water bodies: Reviving small rivers, rivulets, wetlands, and removing encroachments from tanks and lakes.

❖ **Renovation of Traditional Water Bodies**

The initiative emphasizes restoring age-old water bodies including tanks, ponds, stepwells, and lakes. Desilting, boundary strengthening, and channel cleaning activities help bring these systems back to life, thereby improving their storage capacity and ecological value.

❖ **Reuse and Recharge Structures**

Under this function, greywater management, soak pits, recharge shafts, and injection wells are created to ensure that excess water is effectively reused and naturally percolated into aquifers. This supports long-term groundwater replenishment and sustainable water resource management.

❖ **Watershed Development**

Integrated watershed activities such as contour trenching, bund formation, and soil-moisture conservation measures are undertaken to reduce erosion, improve soil health, and regulate surface water movement. These efforts help maintain the hydrological balance in rural and semi-arid areas.

❖ **Intensive Afforestation**

Large-scale tree plantation drives are carried out to enhance green cover, reduce soil erosion, and improve the micro-climate. Afforestation supports groundwater recharge by increasing infiltration and contributes to long-term environmental sustainability.

Atal Bhujal Yojana (Atal Jal) is a Central Sector Scheme launched by the Ministry of Jal Shakti in December 2019, the key objective is to **improve** groundwater levels by encouraging water-use efficiency, crop diversification, and the adoption of rainwater harvesting and groundwater recharge techniques.

The Watershed Development Component of **Pradhan Mantri Krishi Sinchayee Yojana** (WDC-PMKSY) its main objectives are to harness and conserve rainwater by constructing structures like check dams, farm ponds, percolation tanks, contour trenches, and recharge pits. These interventions help in reducing surface runoff, improving water infiltration, and increasing the storage capacity of rainwater for agricultural use.

AMRUT (Atal Mission for Rejuvenation and Urban Transformation) focus on urban water conservation including mandatory rooftop RWH in buildings.

It was launched on 25th June 2015 in selected 500 cities and towns across the country. The Mission focuses on development of basic infrastructure, in the selected cities and towns, in the sectors of water supply; sewerage and septage management; storm water drainage; green spaces and parks; and non-motorized urban transport. A set of Urban Reforms and Capacity Building have been included in the Mission.

AMRUT 2.0 will promote circular economy of water through development of City Water Balance Plan (CWBP) for each city focusing on recycle/reuse of treated sewage, rejuvenation of water bodies and water conservation. It will help cities to identify scope for projects focusing on universal coverage of functional water tap connections, water source conservation, rejuvenation of water bodies and wells, recycle/reuse of treated used water, and rainwater harvesting. Based

on the projects identified in CWBP, Mission envisages to make cities 'water secure' through circular economy of water.

MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) focusing employment generation and creation of rural water conservation infrastructure. Construction of RWH structures like percolation tanks, farm ponds, trenches. Like the above mentioned there are number of programs which are working for water security.

Suvarna Jala scheme was a program launched by the Government of Karnataka in 2007 to provide rooftop rainwater harvesting structures to rural government schools.

In the world of growing water scarcity, Due to increase in urban population and unscientific exploitation of fresh water resources, availability of potable water for human consumption is depleting and this will be one of the biggest challenges for society is going to face in future. Conservation & harvesting of fresh water are immediate measures for sustainable development. Rain water harvesting technique is not only option it has become a necessity. By adopting this technique, we can use the water in sustainable way that is using for the present, by without diminishing to the future generation. Let us use every drop of water wisely.

SOIL EROSION AS A SILENT DRIVER OF LAND DEGRADATION

Article ID: AG-VO5-I12-125

***M. Elayarajan, P.Pramila and B. Gokila**

Department of Soil Science and Agricultural Chemistry,
Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

*Corresponding Author Email ID: elayarajan1971@gmail.com

Abstract

Soil erosion is one of the most pervasive yet least recognized environmental challenges confronting India today. Despite being an agrarian nation where soil underpins food security, livelihoods, and ecological stability, nearly one-third of the country's land area is affected by erosion-induced degradation. Unlike sudden disasters such as floods or cyclones, soil erosion progresses silently removing fertile topsoil year after year, diminishing productivity, increasing vulnerability to climate extremes, and threatening long-term sustainability. This article presents a popular technical overview of soil erosion in India, its causes, consequences, interaction with climate change, and the role of conservation measures and national policies. Recognizing soil erosion as a slow disaster is essential for transforming soil conservation from a peripheral concern into a national priority.

Introduction: India's Hidden Soil Crisis

India possesses one of the largest cultivated land bases in the world, supporting nearly 18% of the global population on just 2.4% of the world's land area. This enormous pressure on land resources has led to widespread soil degradation, with **soil erosion accounting for nearly 70% of total land degradation in the country**. According to national assessments, **about 120–147 million hectares** of land in India are affected by erosion due to water and wind. Every year, **more than 5 billion tonnes of soil** are estimated to be eroded, carrying away precious nutrients equivalent to millions of tonnes of fertilizers. Yet, soil erosion rarely features in public discourse, budget debates, or development narratives. The paradox is striking: while India invests heavily in

improving crop yields and irrigation infrastructure, the very foundation of agriculture soil is steadily being lost. This article argues that soil erosion must be recognized not merely as a technical problem, but as a **slow-moving disaster with profound economic, ecological, and social consequences.**

Soil Erosion: Processes and Forms in Indian Landscapes

What is Soil Erosion?

Soil erosion is the physical process of detachment, transport, and deposition of soil particles by natural agents such as water, wind, gravity, and anthropogenic activities. It is a natural geomorphic phenomenon essential for landscape evolution. Under undisturbed natural ecosystems, the rate of soil erosion is broadly balanced by soil formation through weathering of parent material and organic matter accumulation. However, in human-modified landscapes, especially under intensive agriculture, deforestation, and infrastructural development, this balance is severely disrupted. In India, soil formation occurs at a very slow rate less than 1 tonne $\text{ha}^{-1} \text{ year}^{-1}$ due to tropical weathering conditions and limited organic matter buildup. In contrast, soil erosion losses frequently exceed 15–40 tonnes $\text{ha}^{-1} \text{ year}^{-1}$, particularly in rainfed agricultural systems, mountainous regions, and degraded watersheds. Such losses are effectively irreversible on human timescales, leading to long-term declines in soil fertility, water-holding capacity, and biological activity.

Major Types of Soil Erosion in India

India's diverse physiography, monsoonal climate, and land-use intensity give rise to multiple forms of soil erosion. Among these, water erosion, wind erosion, and tillage erosion are the most significant.

a) Water Erosion

Water erosion is the most widespread and severe form of soil erosion in India, driven primarily by high-intensity monsoonal rainfall, steep slopes, and inadequate land cover. It is particularly dominant in:

- Himalayan and sub-Himalayan regions
- Eastern and Western Ghats
- Central Indian Plateau
- Semi-arid rainfed agricultural areas

Water erosion occurs through several distinct but interconnected forms:

i) Sheet Erosion

This is the uniform removal of a thin layer of topsoil over large areas by shallow surface runoff. Although visually less noticeable, sheet erosion is extremely destructive because it selectively removes fine particles rich in organic matter and nutrients, leading to gradual but significant fertility loss.

ii) Rill Erosion

Rill erosion develops when runoff concentrates into small, shallow channels on sloping land. These rills can often be removed by normal tillage, but if left unchecked, they evolve into more severe forms of erosion.

iii) Gully Erosion

Gully erosion represents an advanced stage where runoff cuts deep, wide channels that cannot be easily reclaimed. Gullies fragment agricultural land, reduce usable area, and act as major sediment sources for downstream rivers.

iv) Ravine Erosion

Ravines are extensive networks of deep gullies formed along river systems, especially in alluvial and semi-arid regions. The ravines of the Yamuna, Chambal, and Mahi rivers are classic examples, where intense water erosion has rendered vast tracts of land agriculturally unproductive.

v) Stream Bank Erosion

This occurs along riverbanks due to fluctuating river flows, flood events, and human interference such as sand mining and vegetation removal. Stream bank erosion contributes significantly to sediment load and river instability.

Table 1: Types of Soil Erosion and Key Features

Type of Erosion	Description	Common Regions in India	Impact on Land
Sheet erosion	Thin, uniform soil layer removal	All agricultural lands, rainfed areas	Gradual fertility loss
Rill erosion	Small channels on slopes	Hilly regions, plateau	Reduced cultivable area
Gully erosion	Deep, wide channels	Chambal, Mahi, Yamuna basins	Land rendered unusable
Wind erosion	Detachment by wind	Rajasthan, Gujarat, Haryana	Nutrient depletion, dust storms
Tillage erosion	Soil movement during ploughing	Sloping fields	Topsoil thinning

b) Wind Erosion

Wind erosion is predominant in arid and semi-arid regions characterized by low rainfall, sparse vegetation, and loose, sandy soils. In India, it is most common in:

- Western Rajasthan
- Kutch and Saurashtra regions of Gujarat
- Parts of Haryana and the Deccan plateau

The process involves detachment and transport of soil particles by strong winds, particularly during dry seasons. Fine particles such as clay, silt, and organic matter are preferentially removed, leaving behind coarse, infertile soil. Wind erosion occurs through:

- Suspension, where fine particles travel long distances as dust
- Saltation, involving bouncing movement of sand-sized particles
- Surface creep, where larger particles roll along the ground

Consequences include nutrient depletion, reduced soil moisture retention, dust storms, and progressive desertification.

c) Tillage Erosion

Tillage erosion is a human-induced form of soil erosion caused by repeated mechanical movement of soil during ploughing and cultivation, especially on sloping lands. Unlike water and wind erosion, it occurs even in the absence of rainfall or strong winds.

Repeated upslope and downslope ploughing gradually shifts soil downslope, resulting in:

- Thinning of fertile topsoil on upper slopes
- Accumulation of soil at lower slope positions
- Reduced crop productivity and increased subsoil exposure

Tillage erosion is particularly significant in rainfed agriculture and hill farming systems, where traditional cultivation methods are practiced without contour alignment.

Drivers of Soil Erosion: Human Pressure Meets Climate Stress

Soil erosion in India is driven by the combined effects of human pressure and climate stress. Deforestation, overgrazing, intensive cultivation, and unplanned development expose soil surfaces and weaken their structure. At the same time, erratic rainfall, extreme storms, droughts, and rising temperatures increase the erosive power of water and wind. These factors interact to accelerate soil loss beyond natural recovery rates. Together, they threaten long-term agricultural productivity and environmental sustainability.

Natural Factors

- High-intensity monsoon rainfall
- Undulating and steep topography
- Light-textured and structurally weak soils
- Sparse vegetation during critical periods

Human-Induced Accelerators

Soil erosion in India is largely human-induced, driven by:

- Deforestation and shifting cultivation
- Overgrazing in common lands
- Intensive tillage and residue removal
- Expansion of cultivation into marginal lands
- Unplanned urbanization and infrastructure development

Rainfed agriculture, which covers nearly **52% of India's cultivated area**, is particularly vulnerable due to its dependence on erratic rainfall and fragile soils.

Soil Erosion and Climate Change: A Compounding Threat

Climate change has intensified soil erosion risks across India by altering rainfall patterns and increasing the frequency of extreme events. Short-duration, high-intensity rainfall events now generate excessive runoff, overwhelming the soil's infiltration capacity.

Soil erosion also contributes to climate change by:

- Reducing **soil organic carbon (SOC)** stocks
- Lowering the soil's water-holding capacity
- Increasing land surface temperatures
- Weakening resilience to droughts and floods

India's soils have the potential to act as significant carbon sinks, but erosion-driven loss of SOC undermines this opportunity.

Consequences of Soil Erosion: From Fields to Food Security

Soil erosion leads to the loss of fertile topsoil, reducing crop yields and increasing dependence on chemical inputs. It lowers the soil's water-holding capacity, making farms more vulnerable to droughts and crop failure. Eroded sediments clog rivers and reservoirs, raising flood risks and reducing irrigation efficiency. Over time, land degradation undermines rural

livelihoods and farm incomes. Collectively, these impacts pose a serious threat to national food security and environmental stability.

Decline in Agricultural Productivity

Loss of topsoil directly affects:

- Nutrient availability
- Root growth and microbial activity
- Soil moisture retention

Studies indicate that yield reductions due to erosion range from 5 - 30%, depending on severity and crop type. Farmers often compensate through higher fertilizer use, increasing costs and environmental risks.

Sedimentation of Water Bodies

Eroded soil settles in:

- Reservoirs and tanks
- Canals and irrigation systems
- Rivers and floodplains

India loses substantial reservoir storage capacity annually due to siltation, reducing the effectiveness of irrigation and hydropower projects.

Environmental and Ecological Impacts

- Degradation of soil biodiversity
- Decline in ecosystem services
- Increased non-point source pollution
- Damage to aquatic ecosystems

Socioeconomic Implications

For small and marginal farmers, soil erosion leads to declining incomes, increased vulnerability, and in extreme cases, migration. Land degradation thus becomes both an environmental and social justice issue.

Soil Conservation Strategies: Indian Experience and Solutions

Agronomic Measures

- Contour farming
- Cover crops and green manuring
- Crop diversification and intercropping

- Mulching and residue management

Mechanical and Structural Measures

- Contour bunds and graded bunds
- Terracing in hilly regions
- Check dams and gully plugs
- Grassed waterways

Conservation Agriculture

Minimum tillage, permanent soil cover, and diversified cropping systems have shown promising results in reducing erosion and improving soil health.

Policy Framework and National Programmes in India

India has implemented several initiatives addressing soil erosion:

- Watershed Development Programmes (WDPs)
- Pradhan Mantri Krishi Sinchayee Yojana (PMKSY – Watershed Component)
- National Mission for Sustainable Agriculture (NMSA)
- Soil Health Card Scheme
- National Afforestation Programme

Watershed-based approaches have demonstrated reductions in runoff and soil loss by **30–50%**, while improving groundwater recharge and farm incomes.

The Way Forward: Soil as a National Asset ★★☆☆

Soil as a national asset is essential for India's long-term food and environmental security. Sustainable land-use practices such as conservation agriculture, contour farming, and afforestation must be widely adopted. Integrated watershed management can reduce runoff and restore degraded landscapes. Policies should incentivize soil conservation and support farmers in climate-resilient practices. Protecting soil today ensures productivity, resilience, and sustainability for future generations.

Key priorities include:

- Integrating soil conservation into climate action plans
- Strengthening long-term soil monitoring
- Promoting community participation
- Incentivizing sustainable land management
- Mainstreaming soil education at all levels

Protecting soil is far more cost-effective than restoring degraded lands.

Conclusion

Soil erosion rarely attracts immediate attention because its impacts are gradual and often invisible. Yet, over time, the continuous loss of fertile topsoil severely reduces agricultural productivity, weakens water retention, and disrupts ecosystem functioning. In a country like India where livelihoods, food security, and rural economies are deeply dependent on soil health this slow degradation poses a serious long-term threat.

Unchecked soil erosion diminishes the soil's ability to support crops, increases dependence on external inputs, and accelerates land degradation and desertification. It also contributes to broader environmental problems such as siltation of rivers and reservoirs, increased flood risks, and loss of soil carbon, thereby reducing climate resilience. Recognizing soil erosion as a “slow disaster” requires a fundamental shift from short-term yield maximization to sustainable land and water management. Conservation agriculture, watershed management, afforestation, and climate-resilient farming practices must be prioritized and scaled up.

Saving soil is therefore not merely an environmental concern but a national necessity. The future of Indian agriculture, food security, and ecological stability depends on timely, coordinated, and sustained action to protect this irreplaceable resource.

References

- Bhattacharyya, R., Ghosh, B. N., Dogra, P., Mishra, P. K., Santra, P., Kumar, S., ... & Parmar, B. (2016). Soil conservation issues in India. *Sustainability*, 8(6), 565.
- Edrisi, S. A., Tripathi, V., & Abhilash, P. C. (2018). Towards the sustainable restoration of marginal and degraded lands in India. *Trop Ecol*, 59(3), 397-416.
- Katsir, S., Biswas, A. K., Urs, K., Lenka, N. K., Jha, P., & Arora, K. (2024). Governing soils sustainably in India: Establishing policies and implementing strategies through local governance. *Soil Security*, 14, 100132.
- Panagos, P., Borrelli, P., & Robinson, D. (2020). FAO calls for actions to reduce global soil erosion. *Mitigation and Adaptation Strategies for Global Change*, 25(5), 789-790.

Volume: 05 Issue No: 12

NUTRACEUTICALS FOR STRESS ENHANCEMENT IN FISH: MECHANISMS, SCIENTIFIC EVIDENCE AND AQUACULTURE APPLICATIONS

Article ID: AG-VO5-I12-126

Srinath, E*

PG Scholar, Department of Fish Nutrition and Feed Technology, Kerala University of Fisheries and Ocean Studies (KUFOS), Panangad, Kochi, Kerala

*Corresponding Author Email ID: ssrinathwjd@gmail.com

Abstract

Stress is one of the most critical limiting factors in intensive aquaculture, significantly affecting growth performance, immune competence, antioxidant balance, and disease resistance in fish. Stress responses in fish are primarily regulated through activation of the hypothalamic–pituitary–interrenal (HPI) axis, leading to elevated cortisol secretion and subsequent physiological and metabolic disturbances. Prolonged or repeated stress results in immunosuppression, oxidative damage, impaired gut integrity, and increased susceptibility to pathogens. Nutraceuticals—dietary bioactive compounds that provide health benefits beyond basic nutrition—have emerged as sustainable and eco-friendly strategies to enhance stress tolerance in cultured fish. This article reviews the major classes of nutraceuticals used in aquafeeds, including vitamins, amino acids, fatty acids, probiotics, immunostimulants, and phytochemical compounds, emphasizing their mechanisms of action and scientific evidence supporting their role in stress mitigation and resilience enhancement in fish.

1. Introduction

Aquaculture environments expose fish to a wide range of stressors, including handling, crowding, transportation, poor water quality, temperature fluctuations, hypoxia, nutritional imbalance, and pathogen challenges. In fish, stress triggers a coordinated neuroendocrine response mediated by the hypothalamic–pituitary–interrenal (HPI) axis, culminating in the release of cortisol as the principal stress hormone (Bonga, 1997; Barton, 2002).

While acute stress responses are adaptive and help fish maintain homeostasis, chronic stress leads to negative consequences such as reduced growth, altered metabolism, immune

suppression, oxidative stress, and increased mortality (Wendelaar Bonga, 1997; Schreck & Tort, 2016). Conventional stress-management approaches, including antibiotics and chemotherapeutics, are increasingly discouraged due to environmental concerns, antimicrobial resistance, and regulatory restrictions. Consequently, functional feeds enriched with nutraceuticals have gained significant attention as a preventive and sustainable strategy to improve stress resilience in fish (Dawood et al., 2018).

2. Stress Physiology in Fish

Stress responses in fish occur in three stages: primary, secondary, and tertiary responses. The primary response involves the rapid release of catecholamines and cortisol. Secondary responses include metabolic changes such as hyperglycaemia, altered protein and lipid metabolism, and oxidative stress. Tertiary responses manifest as impaired growth, reduced reproductive performance, immune dysfunction, and increased disease susceptibility (Barton, 2002; Schreck & Tort, 2016).

Cortisol plays a central role in mediating these effects by influencing energy allocation, suppressing immune cell activity, and increasing the production of reactive oxygen species (ROS). Therefore, nutritional strategies that modulate cortisol secretion, enhance antioxidant defences, and support immune function are crucial for stress management in aquaculture.

3. Concept of Nutraceuticals in Aquaculture

Nutraceuticals are dietary components that combine nutritional and pharmaceutical properties, promoting health and disease resistance. In aquaculture, nutraceuticals are incorporated into functional feeds and include vitamins, minerals, amino acids, fatty acids, probiotics, prebiotics, polysaccharides, and plant-derived bioactive compounds (Gatlin et al., 2007; Dawood, 2021).

These compounds enhance stress tolerance by:

- Regulating endocrine stress responses
- Strengthening antioxidant and immune systems
- Improving gut health and microbial balance

4. Major Nutraceuticals for Stress Enhancement in Fish

4.1 Vitamins

Vitamin C (Ascorbic Acid)

Vitamin C is one of the most extensively studied antistress nutraceuticals in fish. As fish

lack the enzyme L-gulonolactone oxidase, dietary supplementation is essential. Vitamin C reduces plasma cortisol levels, enhances phagocytic activity, and protects tissues from oxidative damage induced by handling, transport, and thermal stress (Ai et al., 2006; Dawood et al., 2018).

Vitamin E (α -Tocopherol)

Vitamin E acts as a lipid-soluble antioxidant, protecting cellular membranes from lipid peroxidation during stress. Adequate vitamin E supplementation improves immune responses, reduces oxidative stress markers, and enhances survival under stressful conditions (Tocher, 2015).

4.2 Amino Acids

Tryptophan

Tryptophan is a functional amino acid involved in serotonin synthesis. Increased brain serotonin levels reduce aggressive behaviour and downregulate cortisol secretion. Dietary tryptophan supplementation has been shown to improve stress coping ability in fish exposed to high stocking density and social stress (Hoseini & Yousefi, 2019).

Arginine and Glutamine

Arginine enhances immune responses through nitric oxide synthesis, while glutamine supports intestinal integrity and immune cell metabolism. Both amino acids play crucial roles in maintaining physiological stability during stress (Li et al., 2009).

4.3 Fatty Acids

Omega-3 Polyunsaturated Fatty Acids (PUFAs)

Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) modulate inflammatory responses and improve membrane fluidity. Adequate dietary omega-3 PUFA levels enhance immune competence and reduce stress-induced inflammation in fish (Tocher, 2015).

4.4 Probiotics, Prebiotics and Synbiotics

Probiotics such as *Lactobacillus*, *Bacillus*, and *Enterococcus* species enhance gut microbial balance, digestive enzyme activity, and immune responses. Prebiotics like mannan oligosaccharides (MOS) and fructooligosaccharides (FOS) selectively stimulate beneficial gut microbiota. Synbiotic combinations further strengthen the gut-immune axis, improving stress tolerance and disease resistance (Merrifield & Ringø, 2014; Dawood et al., 2018).

4.5 Immunostimulants and Polysaccharides

β-Glucans

β-glucans derived from yeast and fungi are potent immunostimulants that activate macrophages and enhance respiratory burst activity. Short-term dietary β-glucan supplementation before predictable stress events, such as transport or grading, significantly improves survival and immune competence (Sakai, 1999; Meena et al., 2013).

Chitosan and Chitooligosaccharides

Chitosan exhibits antioxidant, antimicrobial, and immunomodulatory properties. Dietary inclusion improves antioxidant enzyme activity and enhances resistance to stress-induced infections (Dawood et al., 2020).

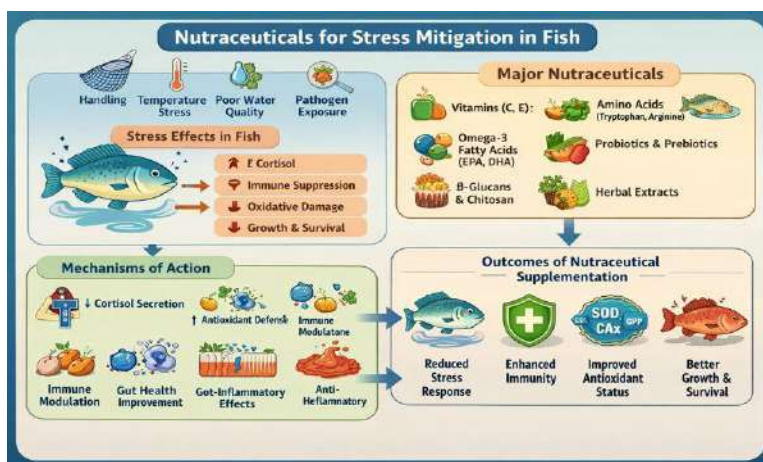
4.6 Phytogetic Nutraceuticals

Plant-derived compounds such as *Withania somnifera*, *Ocimum sanctum*, *Curcuma longa*, garlic, and green tea polyphenols possess adaptogenic, antioxidant, and anti-inflammatory properties. These phytochemicals regulate cortisol secretion, enhance antioxidant enzyme activity, and improve immune responses under stress conditions (Reverter et al., 2014; Van Hai, 2015).

5. Mechanisms of Stress Mitigation by Nutraceuticals

Nutraceuticals enhance stress tolerance through multiple, interrelated mechanisms:

- Downregulation of HPI-axis activity and cortisol secretion
- Enhancement of antioxidant defences (SOD, CAT, GPx)
- Stabilization of cellular membranes and metabolic pathways



- Modulation of gut microbiota and intestinal barrier integrity

- Activation of innate and adaptive immune responses

These mechanisms collectively improve physiological resilience and survival during stress exposure

Conclusion

Scientific evidence clearly demonstrates that nutraceuticals play a vital role in enhancing stress tolerance in fish. By targeting endocrine regulation, antioxidant defence systems, immune responses, and gut health, nutraceuticals provide a sustainable alternative to chemotherapeutics in modern aquaculture. Strategic, species-specific application of nutraceuticals—particularly during predictable stress events—can significantly improve fish welfare, productivity, and economic sustainability. Future research should focus on optimized dosages, synergistic formulations, and molecular-level understanding of nutraceutical–stress interactions.

References

- Ai, Q., Mai, K., Zhang, L., Tan, B., Zhang, W., Xu, W. and Li, H. (2006). Effects of dietary vitamin C on growth and immune response of Japanese seabass under stress. *Aquaculture*, 259, 337–344.
- Barton, B.A. (2002). Stress in fishes: A diversity of responses with particular reference to changes in circulating corticosteroids. *Integrative and Comparative Biology*, 42, 517–525.
- Dawood, M.A.O., Koshio, S. and Esteban, M.Á. (2018). Beneficial roles of feed additives as immunostimulants in aquaculture: A review. *Reviews in Aquaculture*, 10, 950–974.
- Dawood, M.A.O. (2021). Nutritional immunity of fish intestines: Important insights for sustainable aquaculture. *Reviews in Aquaculture*, 13, 642–663.
- Gatlin, D.M., Barrows, F.T., Brown, P. et al. (2007). Expanding the utilization of sustainable plant products in aquafeeds. *Aquaculture Research*, 38, 551–579.
- Hoseini, S.M. and Yousefi, M. (2019). Beneficial effects of dietary tryptophan on stress responses in fish. *Reviews in Aquaculture*, 11, 547–559.
- Li, P., Mai, K., Trushenski, J. and Wu, G. (2009). New developments in fish amino acid nutrition. *Amino Acids*, 37, 43–53.
- Merrifield, D.L. and Ringø, E. (2014). *Aquaculture Nutrition: Gut Health, Probiotics and Prebiotics*. Wiley-Blackwell.

- Reverter, M., Bontemps, N., Lecchini, D., Banaigs, B. and Sasal, P. (2014). Use of plant extracts in fish aquaculture. *Aquaculture*, 433, 50–61.
- Sakai, M. (1999). Current research status of fish immunostimulants. *Aquaculture*, 172, 63–92.
- Schreck, C.B. and Tort, L. (2016). The concept of stress in fish. In: *Biology of Stress in Fish*. Academic Press, pp. 1–34.
- Tocher, D.R. (2015). Omega-3 long-chain polyunsaturated fatty acids and aquaculture. *Aquaculture*, 449, 94–107.
- Van Hai, N. (2015). The use of medicinal plants as immunostimulants in aquaculture. *Aquaculture*, 446, 88–96.

Volume: 05 Issue No: 12

PHYSIOLOGICAL ROLE OF VITAMIN K IN FISH: IMPLICATIONS FOR GROWTH AND SKELETAL DEVELOPMENT

Article ID: AG-VO5-I12-127**Srinath, E**

PG Scholar, Department of Fish Nutrition and Feed Technology, Kerala University of Fisheries and Ocean Studies (KUFOS), Panangad, Kochi, Kerala

*Corresponding Author Email ID: ssrinathwjd@gmail.com

Abstract

Vitamin K is a fat-soluble micronutrient traditionally associated with blood coagulation, but growing evidence highlights its broader physiological importance in fish, particularly in relation to growth performance and skeletal development. In aquaculture species, vitamin K acts as an essential cofactor for the γ -carboxylation of specific proteins involved in calcium binding and bone mineralization. Inadequate dietary vitamin K has been linked to skeletal deformities, impaired ossification, haemorrhagic disorders, and reduced growth in several fish species. With the increasing reliance on plant-based feed ingredients and intensive farming practices, the risk of vitamin K deficiency has become more pronounced. This review summarizes the physiological functions of vitamin K in fish, emphasizing its role in skeletal development, growth regulation, and mineral metabolism, and discusses its implications for modern aquafeed formulation and sustainable aquaculture.

1. Introduction

Vitamins play a critical role in regulating metabolic, physiological, and developmental processes in fish. Among fat-soluble vitamins, vitamin K has received comparatively less attention in fish nutrition research when compared to vitamins A, D, and E. Traditionally, vitamin K has been recognized for its essential role in blood coagulation; however, recent studies have demonstrated that its functions extend beyond haemostasis to include bone formation, calcium homeostasis, and skeletal integrity in fish (NRC, 2011; Krossøy et al., 2007).

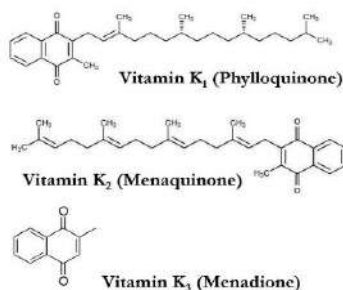
Fish are unable to synthesize vitamin K endogenously and therefore depend on dietary sources to meet their physiological requirements. Vitamin K exists in multiple forms, including phylloquinone (vitamin K₁), menaquinones (vitamin K₂), and menadione (vitamin K₃), with the latter being commonly supplemented in commercial aquafeeds due to its stability and cost-effectiveness (NRC, 2011). Although intestinal microbiota may contribute to menaquinone production, this endogenous supply is often insufficient under intensive aquaculture conditions, particularly when antibiotics or highly refined diets are used (Lall & Kaushik, 2021).

Emerging evidence suggests that vitamin K plays a vital role in skeletal development through the activation of vitamin K-dependent proteins, such as osteocalcin and matrix Gla protein, which regulate calcium deposition and prevent abnormal calcification of bone tissue (Krossøy et al., 2007; Sæle et al., 2015). Deficiency of vitamin K has been associated with increased skeletal deformities, reduced bone mineralization, haemorrhagic symptoms, and impaired growth performance in several fish species, including haddock, seabream, and tilapia (Krossøy et al., 2007; Saleh et al., 2023).

Given the increasing use of plant-based ingredients and low-fishmeal diets in aquaculture, understanding the physiological role of vitamin K has become increasingly important. Ensuring adequate vitamin K nutrition is essential for promoting normal growth, maintaining skeletal health, and improving overall productivity in cultured fish species.

2. Chemical structure and characteristics

The term vitamin K represents a family of compounds that have a common 2-methyl-1,4-naphthoquinone ring but differ in the structure at the 3-position. It contains phylloquinone (vitamin K₁, 2-methyl-3-phytyl-1,4-naphthoquinone, mainly in plants), menaquinones (vitamin K₂, 2-methyl-1,4-naphthoquinones, MKs, mainly in microbial origin), and menadione (vitamin K₃, 2-methyl-1,4-naphthoquinone, synthetic form).



Vitamin K₁ is yellow oil, whereas other K vitamins are yellow crystals. Meanwhile, vitamin K₁ and K₂ are fat soluble, but vitamin K₃ is water soluble. All K vitamins are sensitive to light and alkali, but relatively stable to heat.

3.Sources of Vitamin K

Vitamin K₁(Phylloquinone)

Vitamin K₁, the most common form, is abundantly found in green leafy vegetables and herbs. Kale, parsley, spinach, and green cabbage are excellent sources of vitamin K₁. These plants synthesize vitamin K₁ through photosynthesis, incorporating it into their tissues.

Vitamin K₂ (Menaquinones)

Vitamin K₂ is produced by intestinal bacteria in both humans and animals. It is also found in some fermented foods like cheese, natto (fermented soybeans), and certain types of fish.

Synthetic Vitamin K

The synthetic form of vitamin K includes menadione sodium bisulfite (MSB), menadione nicotinamide bisulfite (MNB), menadione sodium bisulfite complex (MSBC), menadione dimethylpyrimidinol bisulfite (MPB). These synthetic forms are mostly included in fish feed due to their stability.

4.The Vitamin K Cycle

a) Activation

Vitamin K is activated in the liver by a specific enzyme called vitamin K epoxide reductase (VKOR). This enzyme converts vitamin K to its active form, which is necessary for the carboxylation process.

b) γ -Carboxylation

The active form of vitamin K acts as a cofactor for the γ -glutamyl carboxylase enzyme. This enzyme catalyses the addition of a carboxyl group to glutamate residues in specific proteins, known as vitamin K-dependent proteins (VKDPs).

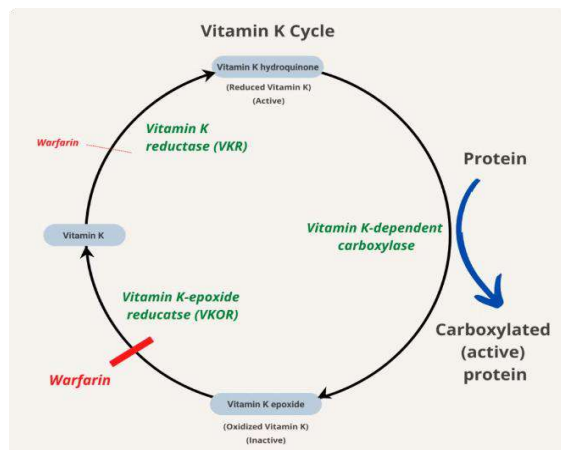
c)Protein Activation

The γ -carboxylation process modifies VKDPs, enabling them to bind calcium ions. This interaction is crucial for their function in blood clotting, bone formation, and other biological processes.

d)Recycling

After participating in the γ -carboxylation reaction, vitamin K is converted to its inactive form,

vitamin K epoxide. This inactive form is recycled back to the active form by VKOR, completing the vitamin k cycle.



5. Physiological Functions of Vitamin K

5.1 Blood Coagulation and Metabolic Regulation

Vitamin K plays a fundamental role in maintaining normal blood coagulation in fish by acting as an essential cofactor for the enzyme γ -glutamyl carboxylase. This enzyme catalyses the post-translational γ -carboxylation of specific glutamate residues in vitamin K-dependent proteins, enabling them to bind calcium ions effectively (NRC, 2011; Sæle et al., 2015). These activated proteins are required for the synthesis of clotting factors such as prothrombin and factors VII, IX, and X, which are essential for proper haemostasis.

Dietary deficiency of vitamin K disrupts this carboxylation process, leading to the production of inactive clotting proteins and resulting in prolonged clotting time, haemorrhages, anaemia, and increased mortality in fish (Krossøy et al., 2007). In aquaculture systems, such impairments can increase susceptibility to handling stress, physical injury, and secondary infections. In addition to its role in coagulation, vitamin K contributes to overall metabolic regulation by supporting normal vascular integrity and physiological homeostasis, emphasizing its importance beyond a single biochemical pathway (NRC, 2011).

5.2 Role in Skeletal Development

In addition to its well-established role in blood coagulation, vitamin K is critically involved in skeletal development and bone mineralization in fish. This function is mediated through the activation of vitamin K-dependent calcium-binding proteins, particularly osteocalcin

and matrix Gla protein (MGP), which play key roles in regulating calcium deposition and bone matrix organization (Sæle et al., 2015).

Osteocalcin facilitates the binding of calcium to the bone matrix, thereby promoting proper mineralization, while MGP acts as an inhibitor of abnormal or ectopic calcification, ensuring that mineral deposition occurs at appropriate skeletal sites (Krossøy et al., 2007). Adequate activation of these proteins is essential for normal vertebral formation, fin development, and overall skeletal integrity.

Experimental studies have demonstrated that dietary vitamin K deficiency results in reduced bone mineral content, poor ossification, and an increased incidence of skeletal deformities. For example, haddock (*Melanogrammus aeglefinus*) fed vitamin K-deficient diets exhibited impaired vertebral mineralization and a higher frequency of deformities (Krossøy et al., 2007). Similarly, studies in gilthead seabream (*Sparus aurata*) larvae have reported that both deficiency and excessive supplementation of vitamin K₃ negatively affect skeletal development and growth performance, indicating the need for optimal dietary levels (Saleh et al., 2023). These findings highlight the crucial role of vitamin K in maintaining skeletal health, particularly during early developmental stages when bone formation is most active.

6. Influence on Growth Performance

Vitamin K is not traditionally classified as a growth-promoting nutrient; however, its contribution to structural development and physiological stability plays an indirect yet significant role in growth performance of fish. Adequate dietary vitamin K supports proper skeletal ossification and vertebral integrity, which are essential for maintaining normal body conformation, swimming efficiency, and feeding behaviour (Sæle et al., 2015).

Fish exhibiting skeletal deformities often show reduced growth rates due to impaired locomotion, inefficient feed capture, and increased energy expenditure. By promoting bone mineralization through activation of vitamin K-dependent proteins such as osteocalcin and matrix Gla protein, vitamin K helps minimize deformities and enhances overall physical performance, thereby indirectly improving growth outcomes (Krossøy et al., 2007).

Several experimental studies have demonstrated that fish fed vitamin K-adequate diets exhibit higher weight gain, improved feed utilization, and reduced prevalence of skeletal abnormalities. For instance, largemouth bass (*Micropterus salmoides*) showed significantly improved growth and physiological status when fed diets containing optimal levels of vitamin K₃

compared to deficient diets (Zhang et al., 2021). Similarly, studies on gilthead seabream (*Sparus aurata*) larvae reported enhanced growth performance and survival at appropriate dietary vitamin K₃ levels, whereas both deficiency and excess negatively affected growth and skeletal development (Saleh et al., 2023).

These findings suggest that maintaining optimal vitamin K levels in aquafeeds is essential for supporting normal growth trajectories, particularly during early life stages when skeletal formation is rapid and nutritional imbalances can have long-lasting effects.

7. Interaction with Calcium and Vitamin D

Vitamin K interacts synergistically with vitamin D and dietary calcium to regulate bone metabolism and skeletal development in fish. Vitamin D plays a primary role in enhancing intestinal calcium absorption and stimulating the synthesis of bone-related proteins, such as osteocalcin. However, these proteins require vitamin K-dependent γ -carboxylation to become biologically active and capable of binding calcium effectively (NRC, 2011; Sæle et al., 2015).

In the absence of adequate vitamin K, osteocalcin and other vitamin K-dependent proteins remain undercarboxylated and functionally inactive, resulting in inefficient calcium utilization even when dietary calcium and vitamin D levels are sufficient (Krossøy et al., 2007). This imbalance can lead to poor bone mineralization, weakened skeletal structures, and increased incidence of deformities, particularly during larval and juvenile stages when skeletal development is rapid.

Experimental studies in marine fish larvae have demonstrated that optimal skeletal development depends on a balanced supply of vitamin K, vitamin D, and calcium, whereas excess or deficiency of any one of these nutrients can negatively affect bone health and growth performance (Saleh et al., 2023). These findings highlight the importance of considering nutrient interactions rather than individual micronutrients when formulating aquafeeds aimed at supporting skeletal integrity.

8. Contribution of Intestinal Microbiota

The intestinal microbiota of fish can contribute to vitamin K nutrition through the synthesis of menaquinones (vitamin K₂), which may partially meet the host's physiological requirements. This microbial contribution has been documented in several fish species and is considered a supplementary source of vitamin K under natural feeding conditions (Lall & Kaushik, 2021).

However, under intensive aquaculture practices, the contribution of intestinal microbiota to vitamin K supply is often insufficient. Factors such as highly refined diets, limited dietary diversity, environmental stress, and the use of antibiotics can disrupt microbial populations and reduce endogenous menaquinone production (NRC, 2011). As a result, reliance on microbial synthesis alone is unlikely to meet vitamin K requirements, particularly during early developmental stages or periods of rapid growth.

Therefore, dietary supplementation of vitamin K remains essential to ensure adequate physiological availability, support normal skeletal development, and maintain overall health in cultured fish species. Understanding the interaction between dietary vitamin K and gut microbiota may offer future opportunities to optimize vitamin K nutrition through functional feeds or probiotic strategies (Lall & Kaushik, 2021).

9. Antimetabolites and Inactivation of Vitamin K

Vitamin K-dependent physiological processes can be disrupted by antimetabolites that interfere with the vitamin K cycle, thereby inhibiting the activation of vitamin K-dependent proteins (VKDPs). Among these compounds, warfarin is the most well-known vitamin K antagonist and has been extensively used as an anticoagulant in clinical medicine. Warfarin exerts its effect by inhibiting the recycling of vitamin K to its biologically active form, ultimately impairing γ -carboxylation-dependent processes (Shearer, 2009; Suttie, 2014).

Warfarin specifically targets vitamin K epoxide reductase (VKOR), the enzyme responsible for converting vitamin K epoxide back to reduced vitamin K during the vitamin K cycle. Inhibition of VKOR prevents the regeneration of active vitamin K, leading to a functional vitamin K deficiency even in the presence of adequate dietary intake (Suttie, 2014). As a result, the activity of γ -glutamyl carboxylase is reduced, limiting the carboxylation of glutamate residues in VKDPs.

Reduced γ -carboxylation leads to the formation of undercarboxylated VKDPs, which exhibit diminished calcium-binding capacity and compromised biological activity. In particular, undercarboxylated clotting factors such as prothrombin become less effective, resulting in impaired blood coagulation and prolonged bleeding time (Shearer, 2009). This anticoagulant effect forms the basis for the therapeutic use of warfarin in preventing thromboembolic disorders.

In fish, experimental exposure to vitamin K antagonists or dietary vitamin K deficiency has been shown to induce haemorrhagic symptoms, skeletal abnormalities, and impaired physiological homeostasis, highlighting the essential role of an intact vitamin K cycle in maintaining normal metabolic and structural functions (Krossøy et al., 2007; Sæle et al., 2015). These findings emphasize that disruption of vitamin K metabolism—whether through dietary insufficiency or antimetabolite exposure—can have profound consequences for fish health, growth, and skeletal development.

10. Deficiency Symptoms

Vitamin K deficiency in fish leads to haemorrhages and delayed blood clotting. Skeletal deformities and poor bone mineralization are common. Growth rate is often reduced. Fish may show increased susceptibility to physical stress. Internal bleeding may occur in severe cases. Fin erosion and impaired wound healing are possible. These symptoms emphasize the need for adequate vitamin K in aquafeeds.

11. Clinical Assessment

Vitamin K nutritional status in aquatic animals can be assessed through blood clotting time, g-glutamyl carboxylase activity, and vitamin K epoxide reductase gene expression. In mammals, biomarkers include plasma phylloquinone, prothrombin time, plasma undercarboxylated vitamin K dependent proteins, and urinary Gla excretion (Booth and Al Rajabi, 2008). Plasma phylloquinone can be measured using HPLC method.

12. Implications for Aquaculture Nutrition

Plant-based and low-fishmeal diets can increase the risk of vitamin K deficiency. Proper supplementation is crucial to maintain health. Stability of vitamin K during feed processing must be considered. Species-specific requirement studies help optimize supplementation. Adequate vitamin K supports growth and skeletal integrity. Deficiency can affect overall productivity. Nutrition strategies must address this to ensure healthy cultured fish.

Conclusion

Vitamin K is essential for blood coagulation, bone mineralization, and skeletal development. It supports growth performance in fish. Deficiency leads to deformities, haemorrhages, and reduced productivity. Modern aquaculture diets may lack sufficient vitamin K. Supplementation strategies are therefore important. Ensuring adequate levels enhances fish health and yield. Overall, vitamin K is a key nutrient for sustainable aquaculture.

References.

- Krossøy, C., Waagbø, R., Ørnsrud, R., & Lock, E. J. (2007). Vitamin K deficiency inhibits mineralization and enhances deformity in vertebrae of haddock (*Melanogrammus aeglefinus*). *Aquaculture*, 263(1–4), 270–278.
- Lall, S. P., & Kaushik, S. J. (2021). Nutrition and metabolism of minerals in fish. *Animals*, 11(9), 2711.
- NRC (National Research Council). (2011). Nutrient Requirements of Fish and Shrimp. National Academies Press, Washington, DC.
- Sæle, Ø., Nordgreen, A., Olsvik, P. A., & Hamre, K. (2015). Vitamin K-dependent proteins and their role in skeletal development of fish. *Journal of Fish Biology*, 87(3), 748–765.
- Saleh, R., Fernández, I., Hontoria, F., & Izquierdo, M. (2023). Deficiency and excess in dietary vitamin K₃ affect growth performance and bone health in gilthead seabream (*Sparus aurata*) larvae. *Aquaculture*, 563, 739021.
- Shearer, M. J. (2009). Vitamin K antagonists: Mode of action, clinical applications, and health implications. *Nutrition Reviews*, 67(9), 546–556.
- Suttie, J. W. (2014). Vitamin K-dependent carboxylase. *Annual Review of Nutrition*, 34, 1–22.
- Zhang, X., Li, Y., Wang, J., & Chen, D. (2021). Effects of dietary vitamin K₃ on growth performance, coagulation parameters, and antioxidant capacity in largemouth bass (*Micropterus salmoides*). *Aquaculture and Fisheries*, 6(6), 602–609.

Volume: 05 Issue No: 12

PREDICTIVE ANALYTICS FOR FOOD SHELF-LIFE: USING ARTIFICIAL INTELLIGENCE TO REDUCE MEAT AND POULTRY LOSSES IN INDIA

Article ID: AG-VO5-I12-128**Sivakumar K and Pavithra G***

VOC Agricultural College and Research Institute, Killikulam, Tamil Nadu, India

*Indian Institute of Management Ahmedabad, Gujarat, India

*Corresponding Author Email ID: f25pavithrag@iima.ac.in

Abstract

India's expanding meat and poultry sector continues to face significant post-harvest losses due to spoilage, temperature fluctuations and inadequate monitoring systems. Traditional expiry dates, fixed under ideal storage conditions, fail to reflect the actual handling environment encountered across India's fragmented cold chain. This leads to inaccurate shelf-life estimation, financial losses and food safety risks. Predictive analytics, supported by artificial intelligence (AI) and machine learning (ML), offers a scientific approach to modelling spoilage by analysing temperature patterns, microbial dynamics, biochemical indicators and packaging attributes. This article explains the role of AI-driven shelf-life prediction in modernising India's meat value chain and discusses its practical applications, challenges and future potential. By integrating technological insight with managerial perspectives, the article highlights how predictive analytics can strengthen food safety, reduce wastage and enhance decision-making across processing, transportation and retail segments of the poultry and meat industry.

Keywords: Predictive shelf life, Artificial intelligence, Meat quality, Poultry, Cold chain, Machine learning

Introduction

India is currently witnessing rapid growth in the demand for poultry and meat products, driven by rising incomes, urban dietary shifts and increased preference for hygienic protein sources. Despite this growth, spoilage remains a persistent challenge, primarily due to the country's under-developed cold chain infrastructure. Only a small proportion of meat products

are transported under controlled refrigeration, leading to temperature abuse, microbial contamination and quality degradation. Temperature fluctuations between 8°C and 12°C- common during transport-can reduce shelf life drastically, making traditional “Use By” and “Best Before” dates unreliable for Indian supply chains. The sector loses nearly 12-15% of meat annually, resulting in reduced profitability and posing potential food safety risks. These challenges demand a transition from fixed expiry systems to dynamic, data-driven models that reflect the actual conditions experienced by each batch. Predictive shelf-life modelling using AI and ML has emerged as a technologically advanced solution capable of addressing these issues.

Mechanisms of Spoilage in Meat and Poultry

Spoilage in meat results from complex biological and chemical processes that accelerate quickly in unsuitable conditions. Temperature is one of the most critical determinants of spoilage. As shown in Figure 1, poultry stored at 0°C may remain fresh for up to ten days, but the shelf life reduces to nearly two days when the temperature reaches 10°C. This reduction is linked to the rapid multiplication of spoilage microorganisms. Microbial growth follows an exponential pattern, as seen in Figure 2, where bacterial counts rise dramatically from 10 CFU/g to nearly 200,000 CFU/g within thirty hours at 8°C. Such exponential growth, often invisible to the naked eye in early stages, significantly accelerates spoilage. Chemical changes also contribute to reduced freshness. Fresh meat undergoes a gradual decline in pH from 6.8 to 5.6 within the first twenty-four hours, as illustrated in Figure 3. Similarly, Total Volatile Nitrogen (TVN), an indicator of protein breakdown, increases steadily during storage, signalling the onset of spoilage (Figure 4). These temperature, microbial and biochemical indicators form the scientific foundation of predictive shelf-life models.

Predictive Shelf-Life Modelling Using Artificial Intelligence

AI-based shelf-life prediction relies on integrating sensor data, laboratory results and environmental conditions to estimate how long a meat product will remain safe for consumption. Time-temperature integrators installed in cold rooms, vehicles or packaging continuously record temperature variations, allowing ML models to calculate the cumulative thermal load experienced by the product. This data helps determine the rate at which bacterial growth is likely to accelerate. Microbial behaviour models analyse how quickly microorganisms multiply under different oxygen, temperature and humidity conditions. Chemical predictors such as pH, TVN and lipid oxidation values are incorporated into neural network algorithms to provide a detailed

understanding of spoilage progression. Deep learning techniques such as Convolutional Neural Networks assist in analysing surface characteristics including colour fading, texture loss and drip formation. These visual changes, often unnoticed by human inspection, offer accurate cues about product freshness. By combining all these factors, predictive analytics systems generate a real-time estimation of remaining shelf life that adapts dynamically based on actual conditions.

Applications of Predictive Analytics in India's Meat Value Chain

The integration of AI-based shelf-life modelling can transform several areas of the poultry and meat value chain. One significant application is the development of dynamic expiry labels, which replace static dates with freshness scores generated from environmental data. Such labels help retailers identify products that must be sold or discounted early, thereby reducing waste. Predictive routing is another area where AI adds value by suggesting transport routes and cooling strategies that minimise exposure to high temperatures. In retail environments, predictive systems assist in inventory management by indicating when batches are likely to spoil, allowing managers to optimise product placement, replenishment and pricing decisions. Exporters can use predictive analytics to ensure compliance with international cold chain standards, reducing the risk of shipment rejection. E-commerce meat delivery platforms also benefit by monitoring temperature throughout the last-mile delivery process, ensuring the product reaches consumers in safe condition. Collectively, these applications improve efficiency, enhance traceability and strengthen consumer confidence in meat products.

Relevance to India's Food Industry and Management Perspective

From a managerial standpoint, predictive analytics offers multiple advantages. Loss reduction improves profit margins and provides a competitive advantage in an industry where wastage significantly affects operating costs. Real-time temperature monitoring and predictive alerts increase transparency across supply chain nodes, enabling managers to make faster and more informed decisions. Predictive systems also enhance food safety compliance, as data logs can be used during regulatory audits to demonstrate proper handling. The adoption of dynamic shelf-life models aligns with the increasing digitalisation of agriculture and food supply chains and supports traceability initiatives. With the rapid growth of India's organised retail and meat e-commerce sectors, predictive analytics will play a vital role in building efficient, technology-driven operations. For academic and professional institutions such as IIM Ahmedabad, understanding the integration of AI into food systems represents an important intersection of

management, technology and agricultural value chains.

Challenges in Adoption

Despite their potential, predictive shelf-life models face challenges in the Indian context. The initial cost of deploying sensors and data systems may discourage small retailers and producers. India's cold chain is fragmented, making continuous data collection difficult. Skilled personnel are required to manage and interpret the data generated by AI-based systems. Additionally, the absence of clear government guidelines for electronic expiry labelling poses regulatory constraints. Addressing these challenges requires coordinated efforts between industry players, policymakers and academic institutions to build infrastructure, training programs and regulatory frameworks that support large-scale adoption of predictive analytics.

Future Scope

The future of predictive shelf-life modelling in India lies in integrating AI with emerging technologies. IoT-enabled smart packaging can provide real-time freshness monitoring directly on the product. Blockchain systems combined with AI can offer end-to-end traceability, allowing consumers to access the complete handling history by scanning a QR code. AI-based grading tools implemented at slaughterhouses can classify carcasses more accurately than manual inspection, improving quality consistency. Digital twins of cold storage rooms can simulate cooling performance and energy usage, enabling facilities to operate more efficiently while preserving product freshness. These advancements will collectively drive India's meat and poultry value chain towards global standards of quality, safety and efficiency.

Conclusion

Predictive analytics supported by AI and ML has the potential to transform India's poultry and meat sector by addressing the long-standing challenges of spoilage, temperature abuse and supply chain inefficiencies. By shifting from static expiry labels to data-driven dynamic models, food businesses can significantly reduce waste, improve profitability and strengthen consumer trust. The adoption of such technologies is essential for building a resilient and modern food system that aligns with India's growing demand for safe and high-quality protein sources. As the agricultural and food industries evolve, predictive shelf-life modelling will become a cornerstone of sustainable, technology-enabled supply chain management.

Volume: 05 Issue No: 12

MICROFLUIDIC AN INNOVATIVE TECHNOLOGY FOR BIOLOGICAL ASSAYS IN DRUG DISCOVERY: EMPHASIS ON MICROCHIP ELECTROPHORESIS

Article ID: AG-V05-I12-129**Baibhav Anand¹, Tanu Shiri^{2*} and Sourabh Jain²**¹Department of Biotechnology, Monad University, Hapur²S.D. College, Muzaffarnagar-251001, (UP) India

*Corresponding Author Email ID: tanushri240@gmail.com

Abstract

The animal experiments are extreme necessity for preclinical screening in drug discovery process which may involve the various issues such as ethical consideration and specific differences. In order to neutralize these issues, cell-based assays using human derived cells have been actively used. These in-vitro cell-based assays show two major applications in drug discovery process such as investigation of seed molecule and assessment of safety. However, it is still remaining difficult to accurately predict drug efficacy, toxicity and organ interactions as the cultivated cells could not retain their original organ functions and morphologies in conventional in vitro cell culture systems. In biochemical engineering, the technologies of Organ chip which is based microfluidic devices being built by using micro fabrication. The researchers have become able to mimic the in-vitro environment by using microfluidic device technology, cellular function maintenance and replication of organ interaction can also be realized using Organ chip devices. Functions of various organs and tissues such as the lung, liver, gut and kidney have been reproduced as in-vitro models so far. Also, a body chip integrating a multi organ function on a microfluidic device has been proposed for prediction of organ interactions. This evaluation provides a background of microfluidic systems organ chip or body chip technology and their challenges in the future.

Keywords: Drug discovery, Cell based assay, Micro fluid, Animal testing, organ chip

Introduction

Animal testing plays a crucial role in prediction of what the body does to the drug known

as pharmacokinetics which is a preclinical test in drug discovery. The information obtained by animal testing helps in predicting the efficacy and toxicity of a drug candidate in the human body. However, animal testing for cosmetic development has been prohibited since 2013 in European Union (EU). This could also reduce and prohibit the use of animal testing in drug discovery in near future. So, currently human derived cells are used in vitro tests as an alternative to animal testing. However, these methods have shown some problems such as the cultured cells in petri dishes and multi well plates markedly losing their responsiveness and function which make it difficult as the interactions between organs cannot be directly evaluated. Thus, there are some major differences between information obtained from animal testing and conventional in-vitro tests for pharmacokinetics predictions.

Nowadays, Organ chip based on microfluidic technology has been used as a novel cell-based assay tool in the μ TAS (Micro Total Analysis Systems) research area. However, in recent years, large scale research industries have been allocated to research projects regarding Organ chip technology. In this paper the review is on how the Organ chip works and discussion for practical application of these innovative technologies during drug discovery.

Microfluidic Technology Meets Cells

Microfluidic devices are used in chemical reactions and are fabricated by semiconductor micro fabrication like photolithography and soft lithography. The technology is called 'lab-on-a-chip' or simply as 'microfluidics' and was established as an interdisciplinary field of research by combining Nano or micro device Technologies, analytical chemistry and chemical sensor Technology. In general culture cell lines in vitro are inactivated and without any physiological function. This loss or deactivation of cellular functions in cultures is due to some difference between morphology and environment of in-vivo & in-vitro conditions. In order to fill this large gap between in-vivo and in-vitro conditions, the researchers have been working in the μ TAS and using microfluidic devices to cell culture applications. Organ chip technology utilizes this microfluidic approach to replicate organ functions, it has attracted a great amount deal of attention in recent time. Due to the further progress of a differential induction method for iPS cells, tissue models along with the disease models for drug discovery using Organ chip technology have been proposed and expected to serve as base for cell-based assays during drug discovery.

Organ chip research has showed some improvements even in the initial stages of its application. The improvement can be seen in the functional activity by perfusion culture of 3D hepatocyte aggregations and observation of responses vascular endothelial cells to medium flow in a micro channel. Due to the advancement in micro fabrication, cell imaging technologies have helped Organ chip in becoming an innovative technology which is capable of reproducing physiological cell behavior in vitro. Although in recent times, a significant number of research grants have been invested in Organ chip projects from the National Institute of Health (NIH), the Food and Drug Administration (FDA) and Defense Advanced Research Projects Agency (DARPA) in the USF. This type of investment also shows the magnitude of expectations for research related to Organ chip technology.

Organ chip

The μ TAS researchers have recently developed Organ chip devices that reproduce various behaviors of various organs and tissues. We can also introduce some examples of in-vitro research models representing major organs such as the lung, liver, kidney and gut in this review.

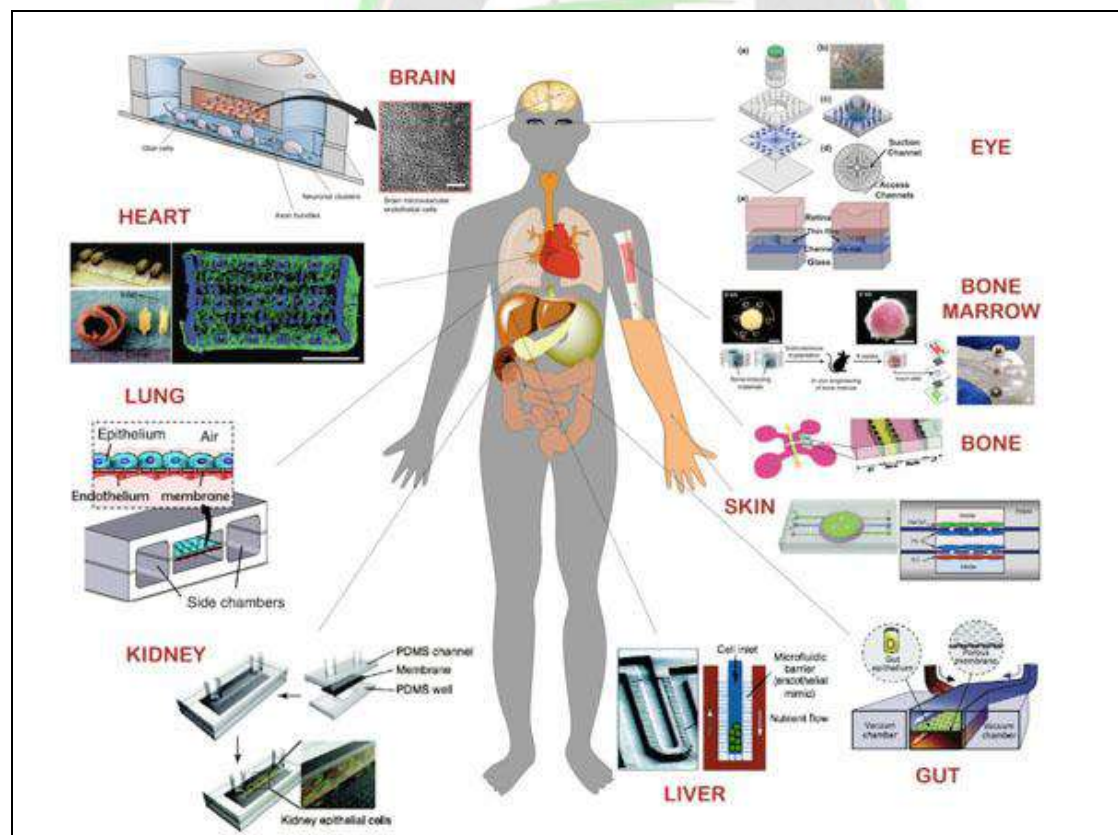


Fig 1: Organ Chip development by biomaterials (Source: Vivekanandan, 2018)

1. Lung chip

This one is the most famous Organ chip known as “breathing lung” developed at Harvard University. This device was made up of a two layered channel structure which was vertically separated by a microsporous stretchable silicone and polymethylsiloxane (PDMS) membrane. They cultured alveolar epithelial cells on the upper and vascular epithelial cells on the lower surface of the membrane. The use of flowing air and culture medium was done to replicate the lung structure on a microfluidic device. But the physiological expansion and contraction movements of the alveolus during respiration was not easy to mimic. So, it was achieved by changing the internal pressure of the channel on both sides of the main channel at a specific cycle in order to extend and contract the porous membrane. The reproduction of inflammatory reaction is done in which vascular endothelial cells highly express the integrin ligand (ICAM-1) after exposure of cells to tumor necrosis factor (TNF α) and bacteria by using this device. In addition to this, the neutrophils flowing in the vascular side channel which is attached to the vascular endothelial cells following the expression of ICAM-1, then migrated to the alveolar epithelial cell surface side, through the vascular endothelial cells and the membranal pores phagocytized by bacteria. A toxicity test is being done by using nanoparticles showed that the amount of nanoparticle uptake into the blood vessel side of the device was increased by stretching movements of the membrane. A different study has created a disease model that reproduced symptoms of pulmonary edema with the device. When a drug with low molecular weight was used in pulmonary edema treatment in this disease model, inhibition of extravasation was seen similar to that observed in a pulmonary edema model animal. This device format has been widely applied to other organs such as gut and kidney.

2. Liver-on-a-chip

Since, the principal organ related to drug metabolism is the liver, it becomes extremely important to predict its metabolic ability and toxicity quite accurately during the drug discovery process. Hepatocytes however used for in-vitro screening lose many of their original functions and activities. Powers and his colleagues proposed a microfluidic device that allows morphogenesis of 3D tissues structures under continuous perfusion. A cell culture chamber was designed which makes the flow rate meet the estimated values of cellular oxygen consumption while maintaining fluid shear stress within the physiological range. Although, It is also important to maintain the polarized transport ability of hepatocytes in order to investigate the drug

responses. Nakao have developed a hepatic lobules module device that reproduced the microstructure of the hepatic cord. It was shown that aligned hepatocytes gradually self organize and form bile canaliculi along with some hepatic cord like structures. Later, a drug metabolism test using carboxydichlorofluorescein diacetate (CDFDA) as a model metabolize was performed as a drug response evaluation. When the culture media containing CDFDA were perfused in the blood flow channel, excretion of carboxydichlorofluorescein (CDF) into the bile canaliculi continuously formed between the cells was observed. This proves that in vivo functions such as metabolic pathways that maintain the shape and polarity of tissues can be reproduced by mimicking the microstructure in vivo.

3. Kidney-on-a-chip

The kidney is the organ which responsible for metabolisms and excretion in vivo. Drug candidate efficacy and toxicity in kidney are evaluated exclusively by animal testing in the name of drug discovery. However, drug dropouts in clinical traits due to the metabolical differences in mechanism between humans and experimental animals lead to a quite large loss in drug development costs. These losses can be overturned by doing accurate identification of nephrotoxic compounds at the preclinical testing stage which would allow a significant cost reduct and effectively avoiding nephrotoxic drugs during development.

In the simplest form of a kidney-on-a-chip device, Madin-Darby canine kidney epithelial (MDCK) cells were human kidney-2 (HK-2) cells were adhered to the bottom surface of a micro chemical loaded with some physiological shear stress. This researchers observed an increased cell thickness, expression of Na/K ATPase and even promotion of cilia formation on the cells by the shear stress using this device. This whole data suggested that the physiological behavior of kidney derived cells can be replicated using the appropriate and controlled shear stress load.

Two layered kidney-on-a-chip devices with porous membranes were proposed to renal tubules. During these studies, those physiological responses are related to changes of sodium concentration and osmotic pressure of the apical channel were reproduced by introducing vasopressin and aldosterone type hormones into the basal channel of the device. It was reported that shear stress not only alters cell orientation but also promotes P-glycoprotein expressing cell polarity expression, cilia growth and albumin or glucose absorption in the cells.

Furthermore, in order to mimic a more physiologically accurate structure, a microfluidic device that reproduces the tubular structure of the renal tubule by incorporating a tubular hollow fiber

membrane into a micro channel has been proposed. Lung chip device was applied to replicate the glomerulus structure by using the combination of a human iPS derived podocyte and showed not only the mechanical stimuli like the shear stress but also that the device is applicable as an in-vitro kidney model through an experiment using an anticancer drug. Therefore, not only the lung but the kidney with its extremely complicated structures and functions can be effectively modeled by using Organ chip technology which is an effective approach for reproducing in-vivo tissues structure and function.

4. Gut-on-a-chip

The gut is an organ mainly responsible for digestion and absorption. Particularly, the small intestine functions as a barrier against any drug which is administered orally, it is quite important to predict its function during drug discovery. In order to evaluate this type of function, Kimura with his colleagues developed a small intestine-on-a-chip device which contains an optical detection system. The device consists of two independent compartments separated by a microsporous membrane on which the small intestinal model (Caco-2) cells were cultured. The cells could be cultured for more than two weeks and monolayer transport of rhodamine 123 was monitored successfully by on-chip fluorescent measurement of cell dynamics were realized while using this device, the cell function was not physiological though.

Some scientist proposed another type of gut-on-a-chip device that enables Caco-2 cells to be exposed continuously to physiological mechanical stimuli such as shear stress and cyclic mechanical strain which mimics the peristalsis like movement in vivo. The researchers have showed that the cell cultures by using this device are reprogrammed to undergo spontaneous 3D villus morphogenesis and small intestinal cell differentiation under these physiological conditions. Furthermore, in order replicate more accurate physiological conditions, this device was used to co-culture multiple commensal microbes in contact with epithelial cells of the intestine and to analyze the resulting physiological phenomena. It was demonstrated that this in vitro model replicated results like this from past animal and human studies, so, the researchers concluded that the gut-on-a-chip device can be used to analyze intestinal pathophysiology and dissect disease mechanisms in vitro.

5. Body-on-a-chip

Humans are composed of organs and tissues and possesses multiple physiological roles

and represent a unique kind of complex system. Since, it is very difficult to predict the interactions between organs and tissues using conventional in-vitro cell culture approaches, hence the animal tests are conducted to predict pharmacokinetics. In Organ chip research area, microfluidic devices consisting the functions of multiple organs and tissues called “human-on-a-chip” are being proposed. These devices might be the key to completely understanding the continuous or linked pharmacokinetic process like ADME (absorption, distribution, excretion, metabolism) of various drug administration routes and the data collected would than may be applied to construct mathematical models for drug efficacy prediction. The Schular’s research group has led body-on-a-chip studies were way ahead of others as they have developed a body-on-a-chip device with multiple organ chambers called as micro cell culture analog (uCCA) and have co-cultured different organ derived cells on the device.

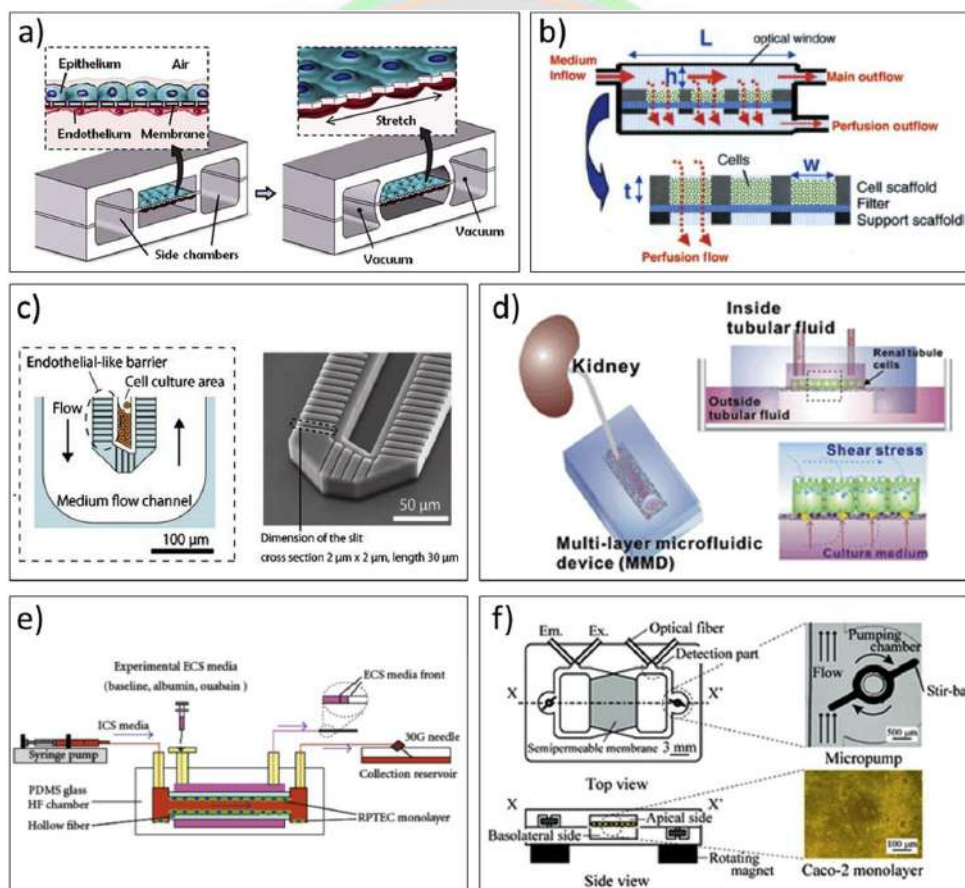


Fig 2: Different Modules for conventional electrical source used for immunomodulation

Scientist explained in his paper that the significance of body-on-a-chip is not only create sophisticated miniature human bodied but to discover the unknown responses that can be

observed only in real time interactions between organs. The data obtained while using these devices should be able to help in improving the accuracy of mathematical models. In another way, body-on-a-chip technology could have a role along with the pharmacokinetics models in the phenomena. It also proposed a method for prediction of cell behavior following exposure to anti-cancer agents by combining the data obtained while using μ TAS and mathematical models to predict pharmacokinetics pharmacodynamics. As a result, they showed the possibility of the combination of body-on-a-chip approach with a mathematical modeling approach.

Advantages of Organ chip technology

- The manufacturing cost is low.
- It allows the testing a wide range of concentration in the dosage of medicine.
- Use of microfluidics makes these chips an interesting and innovative solution for research.
- These are easy to use, portable, small sized and can undergo mass production.

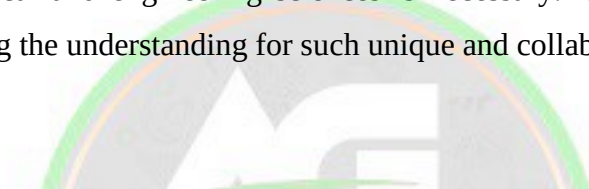
Issues related to practical of Organ chip

There are some new trends being introduced in research related to Organ chip and body-on-a-chip. However, these devices cannot be used directly as an alternative to animal testing. In many other studies which involves Organ chip, the usefulness of these devices was indicated by an evaluation of easily observed and measured functions. However, a practical in-vitro model should be present as a system that can observe and record a variety of physiological responses to specific biological stimuli. To fulfill the requirements, there is a need to develop an observation technology which can evaluate multiply biological responses as well as the biochemical technologies which can perform biochemical analysis in the micro-space of microfluidic devices alongside the Organ chip studies. One of the main biological issue is concerned with the sources of cells to be introduced into Organ chip technology. Although, in previous studies the cell lines and primary culture cells were typically used for evaluation of microfluidic device functions. The immortal cell lines are usually derived from cancerous cells which have lost their original organ functional activity. Although, the primary human derived cells could ideally be used in prediction of highly accurate pharmacokinetics. There are some limitations depending on availability of primary cell cultures due to donor related issues or their cost. On the other hand if human iPS induced cells could be made readily available, the problems regarding the loss of

functional activity would be solved and Organ chip technology would be much closer to practical application.

Conclusion

In this paper, the outlined studies are of Organ chip and body-on-a-chip technologies which could be the required tool in drug discovery. Although, there are no concrete examples yet in which Organ chip technologies have been fully utilized in the actual drug discovering process. A researcher also a pioneer of Organ chip research explained that “Pharma knows what problems it needs to solve but not how to engineer a solution. The engineers know how to build chips but they haven’t thought of the way on how those chips would provide a solution”. The practical use of this technology, active and organic collaboration among different research fields like medical, biological, pharmaceutical and engineering sciences is necessary. It is hoped that this review would help in improving the understanding for such unique and collaborative work.



BIOACCUMULATION AND BIOMAGNIFICATION IN AQUATIC ECOSYSTEMS: PROCESSES, IMPACTS, AND CASE STUDIES

Article ID: AG-VO5-I12-130

D.Manimekalai¹, Dio Snowin², Kavya³ and Babina serlin⁴¹Assistant Professor, Dept. of Aquatic Environment Management, FC&RI, Thoothukudi^{2,3,4} Under Graduate in Fisheries Science (III Year), FC&RI, Thoothukudi, India

*Corresponding Author Email ID: manimekalai@tnfu.ac.in

Abstract

Bioaccumulation and biomagnification are two critical processes governing the movement and intensification of toxic substances in aquatic ecosystems. These processes influence organism health, food web dynamics, biodiversity, and human exposure to hazardous chemicals. Persistent pollutants such as metals, pesticides, and industrial compounds accumulate in organisms and magnify along trophic levels, resulting in severe ecological and health consequences. This article synthesizes mechanisms, causes, impacts, and notable case studies relating to bioaccumulation and biomagnification, emphasizing their significance for environmental monitoring, food safety, and policy interventions.

Keywords

Bioaccumulation; Biomagnification; Aquatic ecosystems; Heavy metals; Persistent organic pollutants (POPs); Food web; Trophic transfer; Environmental toxicology; Human health risk.

1. Introduction

Aquatic ecosystems are increasingly exposed to a wide range of environmental contaminants, including heavy metals, pesticides, microplastics, pharmaceuticals, and persistent organic pollutants (POPs). Once released, these chemicals enter food webs and become incorporated into living organisms. Two key processes—bioaccumulation and biomagnification—explain how contaminants rise to ecologically and physiologically hazardous levels in aquatic biota.

Bioaccumulation refers to the net accumulation of pollutants within an organism through direct uptake from water, sediments, or food. Biomagnification represents the stepwise increase

in contaminant concentration from lower to higher trophic levels. Together, these processes pose significant risks to aquatic life, wildlife, and humans who depend on aquatic resources.

2. Conceptual Framework

2.1 Bioaccumulation

Bioaccumulation is the process by which an organism accumulates chemicals at a rate faster than they are eliminated. Uptake pathways include:

- Direct absorption from surrounding water
- Ingestion of contaminated food
- Dermal or gill absorption
- Sediment contact in benthic species

Fat-soluble and hydrophobic contaminants tend to persist in tissues due to low metabolic degradation and excretion rates.

Common bioaccumulating substances

- Heavy metals: Mercury, cadmium, lead
- Persistent organic pollutants: PCBs, DDT, dioxins
- Microplastics and adsorbed chemicals

2.2 Biomagnification

Biomagnification refers to the increasing concentration of contaminants at higher trophic levels of a food chain. Predators accumulate toxins stored in their prey, resulting in elevated body burdens. Apex predators—including large fish, birds, marine mammals, and humans—experience the highest exposure.

The process occurs due to:

- Inefficient excretion of fat-soluble toxins
- High consumption of contaminated prey
- Long life spans and bioenergetic demands

2.3 Distinguishing the Two Processes

Parameter	Bioaccumulation	Biomagnification
Occurs in	Single organism	Across trophic levels
Source	Water, sediment, diet	Predatory feeding
Timeframe	Lifetime	Ecological generations

Parameter	Bioaccumulation	Biomagnification

Concentration trend	Increases within organism	Increases up food chain

3. Causes of Bioaccumulation and Biomagnification in Aquatic Systems

Anthropogenic activities contribute significantly to pollutant release and persistence:

- Industrial discharge: Metals, PCBs, hydrocarbons
- Agricultural runoff: Pesticides, fertilizers, residues
- Mining activities: Heavy metals (e.g., Cd, Hg, As)
- Urban waste and sewage: Pharmaceuticals, chemicals
- Atmospheric deposition: Global transport of POPs

Many pollutants are **persistent, lipophilic, and resistant to degradation**, favoring long-term accumulation in aquatic organisms.

4. Ecological and Human Health Impacts

4.1 Impacts on Aquatic Organisms

- Bioaccumulated toxins impair metabolic, neurological, and reproductive functions.
- Chronic exposure results in organ damage, endocrine disruption, immunosuppression, and decreased growth and survival.
- Species with higher trophic status show greater contaminant load and vulnerability.

4.2 Impacts on Aquatic Ecosystems

- Disruption of predator–prey dynamics
- Decline of sensitive or keystone species
- Loss of biodiversity
- Altered nutrient cycling and reduced resilience

Persistent pollutants stored in sediments continue to re-enter the food web, causing long-term ecosystem contamination.

4.3 Human Health Implications

Humans are exposed mainly through consumption of contaminated fish and shellfish.

Major health risks:

- Neurological toxicity (mercury, lead)
- Carcinogenic effects (arsenic, PCBs)
- Endocrine disruption

- Developmental abnormalities in infants
- Cardiovascular and reproductive disorders

These impacts underscore the importance of seafood monitoring and pollutant regulation.

5. Case Studies

5.1 Minamata Disease, Japan (Mercury Biomagnification)

Industrial discharge of methylmercury into Minamata Bay resulted in severe mercury biomagnification. Humans consuming contaminated fish developed neurological disorders, birth defects, and fatalities. This incident remains a defining example of trophic magnification of heavy metals.

5.2 PCB and Toxaphene Contamination in the Great Lakes

Long-term industrial pollution led to high PCB and pesticide levels in plankton, fish, and top predators such as bald eagles and seals. Reproductive failures and population declines forced authorities to issue fish consumption advisories.

5.3 Cadmium Bioaccumulation in Asian Wetlands

Agricultural runoff in Thailand and China contaminated wetlands with cadmium. Accumulation in insects, amphibians, fish, and predatory birds demonstrated clear trophic transfer, leading to deformities and reduced reproductive success.

5.4 PCB Accumulation in Killer Whales

Orca populations in the Salish Sea exhibit some of the highest PCB burdens globally. The contaminants stored in blubber interfere with immune function, reproduction, and calf survival, raising conservation concerns.

5.5 Arsenic Accumulation in Freshwater Mussels

Mining activities in the Clark Fork River (USA) introduced arsenic into sediments. Filter-feeding mussels accumulated arsenic, resulting in reduced growth, increased mortality, and food safety risks.

6. Discussion

The reviewed literature and case evidence confirm that bioaccumulation and biomagnification pose widespread risks to aquatic ecosystems and associated human communities. Despite global regulatory measures, many pollutants remain in circulation due to their persistence and transboundary movement. Monitoring programs, stricter waste management practices, and advancement of eco-toxicological assessments are essential for risk mitigation.

Emerging contaminants—such as microplastics, pharmaceuticals, and endocrine-disrupting chemicals—require special attention due to their increasing prevalence and uncertain long-term impacts.

Conclusion

Bioaccumulation and biomagnification represent critical ecological and public health concerns in aquatic environments. Persistent pollutants, once released, enter food webs and magnify across trophic levels, ultimately exposing humans to harmful concentrations. Strengthening pollution control policies, promoting environmentally responsible agriculture, and enhancing ecosystem monitoring are vital to prevent long-term ecological degradation and safeguard human health.

References

1. Bioaccumulation of Xenobiotic Compounds.
2. Bioaccumulation: New Aspects & Developments.
3. Bioaccumulation of Metals in Cyanobacteria.
4. Bioconcentration, Bioaccumulation, Biomagnification and Trophic Magnification: A Modelling Perspective.
5. Bioaccumulation and Biomagnification of Microplastics in Marine Organisms: A Review and Meta-analysis.
6. Minamata Disease Revisited: Acute and Chronic Manifestations of Methylmercury Poisoning.

Volume: 05 Issue No: 12

BUZZING PROSPERITY: THE HONEYBEE'S TRANSFORMATIVE ROLE IN INDIAN AGRICULTURE AND ECONOMY

Article ID: AG-VO5-I12-131

N Vani*

Chief Manager (Research), State Bank Institute of Rural Development
Serilingampalli Post, Opp to Central Hyderabad University, Hyderabad 50019, India

*Corresponding Author Email ID: vanibank1999@gmail.com

Introduction

In the heart of India's agricultural landscape, where vibrant fields of mustard and orchards of mango thrive, the honeybee emerges as a silent yet powerful force. Far beyond their role as honey producers, honeybees are vital pollinators that enhance crop yields, support rural livelihoods, and sustain biodiversity. Beekeeping, or apiculture, is an ancient practice in India, with roots in Vedic texts and prehistoric rock art. Today, it is a burgeoning industry with immense agribusiness potential, bolstered by government initiatives and a growing global market. This article explores the multifaceted role of honeybees in Indian agriculture, delving into their contributions to pollination boosting crop yields, biodiversity, and rural livelihood. For millennia, mankind has practiced the art of beekeeping. Approximately 10,000 years ago, humans began domesticating wild bees by housing them in a variety of man-made hives, such as hollow logs, wooden containers, clay pots, and woven straw baskets called skeps.

"If the bees disappeared from the surface of the globe the man would only have four years of life left. No more bees, no more pollination, no more plants, no more animals, no more man"

- Albert Einstein

Beekeeping is being practiced for various reasons which include:

1. **Honey Collection:** The primary purpose is to collect **honey** from the hives.
2. **Other Hive Products:** In addition to honey, beekeepers also harvest other hive products such as **beeswax, propolis, bee pollen, and royal jelly**.

3. **Pollination:** Bees play a crucial role in **pollinating crops**, so some beekeepers provide pollination services to farmers.
4. **Queen Rearing:** Beekeepers may raise **queen bees** for sale.
5. **Package Bees:** Some beekeepers produce and sell **package bees**, which are used to start new colonies.

Modern Beekeeping: Today, beekeeping is not only about honey production but also serves other purposes. It is utilized for crop pollination, while beekeepers also harvest valuable secondary products such as beeswax and propolis. Large-scale beekeeping operations are common in agriculture, but many small-scale beekeepers pursue it as a hobby. Interestingly, urban beekeeping has become a growing trend, with city-kept bees often healthier due to fewer pesticides and greater biodiversity in urban areas. Beekeeping is the 5th and most important input for overall sustainable development of Agriculture/ Horticulture.

The Pivotal Role of Honeybees in Agriculture

1. Pollination: The Backbone of Crop Productivity- Honeybees are nature's most efficient pollinators, contributing to nearly 85% of global crop pollination services and supporting 34% of the world's food supply. In India, where agriculture employs over 50% of the population, honeybees pollinate a diverse array of crops, including fruits (mango, apple, citrus), vegetables (cucumber, pumpkin), oilseeds (mustard, sunflower), pulses, and fibre crops. Approximately 80% of India's crop plants rely on cross-pollination, making honeybees indispensable for food security and agricultural productivity.

For example, in Himachal Pradesh's apple orchards, pollination deficits once limited yields. Interventions by the Krishi Vigyan Kendra (KVK) and the All India Coordinated Research Project (AICRP) on Honeybees introduced *Apis mellifera* colonies, boosting yields by up to 30%. Similarly, in oilseed crops like rapeseed and sunflower, honeybee pollination increases seed production by 20–40% and enhances oil content, improving both quantity and quality. These gains translate directly into higher farmer incomes and food availability.

Biodiversity and Ecosystem Services: Honeybees also support biodiversity by pollinating wild plants, sustaining ecosystems that underpin agriculture. In India's Northeastern Hill (NEH) region, a rich diversity of bee flora—107 species, including *Brassica* sp., *Solanum* sp., and *Helianthus* sp.—provides nectar and pollen year-round. This floral abundance supports multiple honeybee species, such as *Apis dorsata*, *Apis florea*, and *Apis cerana himalaya*, while ensuring

the pollination of native plants. By maintaining plant-pollinator networks, honeybees contribute to ecological balance and climate-smart agriculture, reducing reliance on chemical inputs and enhancing crop resilience.

Honeybee Species in India: India hosts five commercially significant honeybee species, each adapted to unique ecological niches:

1. **Apis cerana indica:** The Indian honeybee, reared in traditional and modern hives, thrives in hilly and plains regions. It is the cornerstone of small-scale beekeeping.
2. **Apis mellifera:** The Western honeybee, introduced for its high honey yield, dominates commercial beekeeping in states like Punjab and Tamil Nadu.
3. **Apis dorsata:** The rock honeybee, a wild species, builds large open nests and contributes significantly to forest pollination and wild honey production.
4. **Apis florea,** commonly known as the dwarf honeybee, is predominantly found in subtropical plains and is characterized by its docile temperament and comparatively low honey production.
5. **Apis laboriosa:** The Himalayan cliff bee, adapted to high-altitude regions, supports pollination in extreme environments.

Indian Apiculture Market: The apicultural trade in India has witnessed continual and enduring advancement. In 2023, the market size reached INR 25,760.9 million, and it is expected to reach INR 63,474.6 million by 2032, exhibiting a compound annual growth rate (CAGR) of 10.2% during 2024-2032.

Key factors driving this growth include:

1. **Growing Demand for Honey and Bee Products:** Consumers are increasingly aware of the health benefits of honey, leading to higher demand.
2. **Surging Need for Organic Food Products:** As people seek healthier options, organic food products, including honey, are gaining popularity.
3. **Favourable Government Initiatives:** The Indian government promotes beekeeping through various initiatives, which has a positive impact on the market.
4. **Availability of Cheap Labor and Favourable Climatic Conditions:** These factors contribute to the success of beekeeping in India.
5. **Innovative Beekeeping Technologies:** Modern beehives and other advancements are driving growth.

6. **Interest Among Entrepreneurs:** Young entrepreneurs recognize beekeeping as a viable business opportunity.
7. **E-commerce Platforms for Bee Products:** Online platforms facilitate the sale of honey and related products.

Government initiatives: Government Initiatives: The Government of India has launched a Central Sector Scheme known as the “National Beekeeping & Honey Mission (NBHM),” with the objective of promoting and advancing scientific beekeeping in a structured, mission-driven manner. This initiative supports the vision of a “Sweet Revolution” by emphasizing capacity building and training, targeted support for women, and the provision of inputs to enhance beekeeping promotion and honey production. The initiative includes the establishment of Integrated Beekeeping Development Centres (IBDCs), development of related infrastructure, digitization, and online registration processes, along with support for honey processing, value addition, market access, and research and development activities.

- ✓ This initiative aims to foster the holistic development of the beekeeping sector to generate income and employment opportunities, while also providing sustainable livelihood support to both farm and non-farm households. Additionally, it seeks to enhance agricultural and horticultural productivity. The initiative's main components include creating cutting-edge facilities to produce superior nucleus bee stock, growing bee breeding programs, establishing disease diagnostic labs, and creating beekeeping-focused Centers of Excellence (CoEs) or Integrated Beekeeping Development Centers (IBDCs).
- ✓ The initiative also supports the establishment of beekeeping equipment manufacturing units and the development of post-harvest and marketing infrastructure, such as honey processing facilities, storage and cold storage units, collection hubs, branding, and marketing centres.
- ✓ Establishing state-of-the-art quality control labs at the regional level to test honey and honey and other beehive products, as well as mini/satellite labs at the district level in the major honey-producing states and districts.
- ✓ To encourage trade agreements between traders, honey processors, exporters, and beekeepers, among others. To design and implement a blockchain-based traceability system to ensure transparency and verification of the origin of honey and other beehive

products, alongside the integration of digital tools in beekeeping, including provisions for online registration and related services.

- ✓ To establish and support the development of dedicated Honey Corridors in regions with high potential for apiculture.
- ✓ To foster and support the involvement of Agri-entrepreneurs and Agri-startups in beekeeping and honey production ventures.
- ✓ To promote, advance, and disseminate cutting-edge technologies and foster skill development within the beekeeping industry, aimed at enhancing the production of honey and other high-value beehive products.
- ✓ Empowerment of Women through Beekeeping
- ✓ To increase the production of premium honey and other value beehive products for the domestic and international markets, including beeswax, bee pollen, propolis, royal jelly, comb honey, bee venom, etc., in order to diversify into beekeeping and improve economic, ecological, and social benefits; and
- ✓ Creating SHGs, FPOs, Beekeepers Cooperatives, Federations, and other institutional frameworks through a communal approach would help beekeepers become stronger.

Potential and Opportunities: Opportunities and Potential: India holds considerable promise for the expansion and development of the beekeeping industry. Its rich biodiversity and varied flora offer abundant opportunities for the expansion and development of the beekeeping industry. About 150 million bee colonies would need to be deployed, according to the National Commission on Agriculture, in order to pollinate 12 of the nation's most important crops. Currently, 450 million bee colonies are needed to raise their yield, which will boost food production, create 20 million tonnes of honey, and employ 315 lakh people.

Approximately 3.00 lakh people are employed by the approximately 30 lakh bee colonies that currently produce 94500 metric tonnes of honey, including honey from wild honeybees, in India. One of the top nations involved in honey exporting is India. The primary markets for Indian honey include Germany, the United States, the United Kingdom, Japan, France, Italy, Spain, and so forth. Around the world, 14–15 lakh metric tons are produced. Ninety percent of the world's production is produced in 15 countries. China, the United States, Mexico, Argentina, Ukraine, Turkey, Russia, and India are the main producers of honey.

The Honey Market in India

Production and Export Dynamics:

India is a global leader in honey production, with an estimated output of 120,000 metric tons annually. The country ranks among the top honey exporters, with exports valued at approximately US\$200 million in recent years, targeting markets in the United States, European Union, Saudi Arabia, and Southeast Asia. In 2005, exports were valued at US\$26.4 million, reflecting significant growth over the decades. The informal sector, comprising small-scale beekeepers, accounts for 70% of production, while organized players like Dabur, Patanjali, and cooperative societies contribute to branded honey markets.

Honey varieties such as litchi, acacia, and mustard are prized for their distinct flavors, with premium pricing in international markets. The rise of organic and monofloral honey has further boosted export potential, as global consumers increasingly demand natural and sustainable products. However, challenges like honey adulteration with sugar syrups and stringent international quality standards, such as those set by the EU, pose hurdles. More strict rules have been put in place by the Food Safety and Standards Authority of India (FSSAI) to guarantee the purity of honey, enhancing India's standing as a reliable supplier.

Domestic Market Growth:

The domestic honey market is expanding rapidly, driven by growing consumer awareness of honey's health benefits, including its antioxidant and antimicrobial properties. With an estimated market value of around INR 2,000 crore, the honey industry is expected to grow at a compound annual growth rate (CAGR) of 10–12% over the next decade. The increasing urban demand for branded and organic honey, along with the expansion of e-commerce platforms such as Amazon and Flipkart, has opened significant opportunities for beekeepers and honey processors. Cooperative models, such as those supported by the Khadi and Village Industries Commission (KVIC), enable small-scale beekeepers to access urban markets, ensuring better price realization.

Agribusiness Potential of Beekeeping

Low-Investment, High-Return Enterprise:

Beekeeping is an ideal agribusiness for India's rural economy, requiring minimal land, capital, and infrastructure. A single bee colony can be established for as little as INR 5,000, with potential annual returns of INR 10,000–15,000 from honey and by-products like beeswax,

pollen, propolis, and royal jelly. The National Bee Board (NBB) estimates that 10,000 colonies can generate 300,000 man-working days, creating significant employment opportunities for landless farmers, women, and youth.

Beekeeping also offers diversified income streams. Bee products demonstrate exceptional versatility beyond honey—royal jelly enhances nutraceuticals, propolis aids in medical applications, and beeswax plays a key role in cosmetics and candle production. In the NEH region, innovative beekeepers are creating value-added products like beeswax soaps and propolis tinctures, successfully tapping into specialized markets. Migratory beekeeping, where hives are moved to follow blooming seasons, maximizes honey production and pollination services, with migratory apiaries in Punjab reporting incomes 20–30% higher than stationary units.

Entrepreneurship Opportunities:

The beekeeping value chain offers numerous entrepreneurial avenues, from hive manufacturing and queen bee rearing to consultancy services and processing units. Startups such as Beebox and Honey Veda are harnessing technology to introduce IoT-enabled beehives and advanced traceability systems, thereby improving both productivity and transparency in apiculture. The Central Bee Research and Training Institute (CBRTI) in Pune is empowering the next generation of agribusiness leaders by training young entrepreneurs in advanced apiculture techniques.

Rural Empowerment and Inclusivity:

Beekeeping's accessibility makes it a powerful tool for rural empowerment. Women, who constitute 30% of India's beekeepers, are increasingly involved in apiculture, with programs like the KVIC's Honey Mission providing training and equipment. In states like Uttar Pradesh and West Bengal, beekeeping cooperatives have empowered marginalized communities, offering stable incomes and social mobility. The Ramakrishna Mission's beekeeping initiatives in West Bengal demonstrate how community-led models can drive economic and social change.

Government Initiatives Supporting Beekeeping

Launched in 2020 as part of the Atmanirbhar Bharat initiative, the National Beekeeping and Honey Mission (NBHM) aims to boost agricultural productivity through enhanced pollination services while promoting beekeeping as a sustainable and viable livelihood. The mission's INR 500 crore budget is allocated to the establishment of 10,000 additional colonies, the construction of honey testing facilities, and the development of market connections. The

NBB, under the Ministry of Agriculture, registers beekeepers and provides subsidies for hives, equipment, and training. By 2025, the NBHM targets doubling honey production and increasing export revenues by 50%.

Khadi and Village Industries Commission (KVIC): By distributing more over 1.5 lakh bee boxes to farmers, the KVIC's Honey Mission has generated 15,000 jobs and produced 3,000 metric tons of honey yearly. The initiative promotes the production of organic honey while providing beekeepers with training, essential equipment, and access to markets. KVIC's "Honey Corners" in retail outlets and online platforms have boosted domestic sales, while its collaboration with FSSAI ensures quality compliance.

ICAR and Research Support: The Indian Council of Agricultural Research (ICAR), through the AICRP on Honeybees and Pollinators, drives research and extension activities. Established in 1980, the project has developed improved hive designs, disease-resistant bee strains, and pollination protocols. ICAR's 29 centers across India conduct farmer training and awareness campaigns, bridging the gap between research and practice. The CBRTI in Pune serves as a hub for advanced training, offering courses on queen rearing, honey processing, and integrated pest management (IPM).

Additional Programs: The Mission for Integrated Development of Horticulture (MIDH) and the Rashtriya Krishi Vikas Yojana (RKVY) offer financial support for beekeeping infrastructure, including apiaries and processing facilities. State-level initiatives, like Tamil Nadu's Beekeeping Development Program, offer subsidies and technical support to small-scale farmers. These schemes align with India's broader agricultural goals of doubling farmers' incomes and promoting sustainable practices.

Challenges Facing Honeybees and Beekeeping

Pesticide Exposure: Pesticides, particularly neonicotinoids, are a major threat to honeybees, impairing their navigation, immunity, and reproduction. In India, indiscriminate pesticide use in crops like cotton and rice has led to significant bee mortality. A study in Ethiopia, reflective of similar issues in India, reported the loss of 22,987 colonies due to pesticide misuse, equating to an economic loss of \$819,291.37 USD. Sublethal pesticide doses disrupt colony dynamics, reducing queen bee mating frequency and increasing disease susceptibility.

Climate Change: Climate change disrupts floral availability and bee foraging patterns through erratic rainfall, extreme temperatures, and water shortages. The harsh Himalayan winters,

combined with bee-eater birds, pose additional challenges in the region. A study noted that water deficits force bees to prioritize water collection over nectar, reducing honey yields and colony health.

Diseases and Pests: Honeybees face diseases like American foulbrood and deformed wing virus (DWV), spread by pests like the Varroa destructor mite. In southern India, the Thai sacbrood virus decimated 90% of *Apis cerana* populations in the 1990s. Acaricides used to control Varroa harm bee reproduction, creating a cycle of dependency and decline.

Habitat Loss and Deforestation: Urbanization and deforestation reduce bee flora, limiting nectar and pollen sources. In the NEH region, habitat loss threatens wild bee populations, disrupting plant-pollinator networks. The decline of native plants like mustard and sunflower further constrains forage availability.

Market and Quality Issues: Honey adulteration with cheap sugar syrups undermines consumer trust and export potential. Stringent international standards, such as the EU's antibiotic residue limits, require costly testing and compliance. Small-scale beekeepers often lack access to processing facilities and market information, limiting their competitiveness.

Opportunities for Growth

Technological Innovations: Advances in hive design, such as the Newton hive and IoT-enabled smart hives, improve colony management and monitoring. Research into artificial pollinators, while speculative, could complement honeybee pollination in the future. However, experts emphasize that protecting natural pollinators remains the most effective strategy.

Sustainable Practices: Encouraging the adoption of Integrated Pest Management (IPM) and organic farming practices can significantly minimize pesticide exposure. Planting bee-friendly flora, such as clover and lavender, ensures year-round forage. Migratory beekeeping maximizes pollination and honey production, while water management systems mitigate climate impacts.

Certifications and Market Access: Certifications like 'Organic India' and Geographical Indication (GI) tags can greatly boost the market appeal and credibility of Indian honey products. E-commerce platforms and cooperative models offer avenues to directly link beekeepers with consumers, thereby improving price realization.

Community and Policy Support

Collaborative initiatives involving beekeepers, farmers, and policymakers are essential to addressing challenges such as pesticide misuse and habitat degradation. Public awareness

campaigns highlighting the ecological importance of pollinators and the risks associated with agrochemicals can help build broader community engagement. Extending the coverage of initiatives under the National Beekeeping & Honey Mission (NBHM) and the Khadi and Village Industries Commission (KVIC) to underrepresented regions such as Bihar and Odisha have the potential to unlock significant, currently untapped opportunities.

Prospects: Beekeeping holds a promising future in India, with the potential to revolutionize agriculture and uplift rural economies. Scaling up beekeeping to meet the 1.78% annual growth in global pollination demand is critical, particularly for oil crops like soybean and rapeseed. Research into climate-resilient bee strains and low-cost technologies can enhance productivity. Policy reforms, such as stricter pesticide regulations and incentives for organic farming, will protect bee populations. Empowering rural communities through training and market linkages will ensure inclusive growth. By 2030, India aims to double honey production and export revenues, positioning itself as a global leader in apiculture. Achieving this vision requires sustained investment, innovation, and collaboration. The honeybee, with its remarkable ability to pollinate, produce, and prosper, holds the key to a sustainable and prosperous agricultural future.

Conclusion

The honeybee is a catalyst for India's agricultural and economic transformation. Its role in pollination, biodiversity, and rural empowerment underscores its importance, while its agribusiness potential and market growth signal a vibrant future. While initiatives like the NBHM and KVIC's Honey Mission offer vital support to beekeeping, urgent action is needed to address pressing challenges such as pesticide use, climate change, and habitat loss. By embracing sustainable practices, leveraging technology, and fostering community engagement, India can ensure that its honeybees continue to buzz, delivering prosperity to farmers, ecosystems, and markets alike. In summary, apiculture is a thriving industry with growing demand for honey, beeswax, and other bee-related products. The apiculture market offering exciting opportunities for both beekeepers and consumers. Thus, Beekeeping encompasses both the art and science of managing bee colonies, offering significant advantages to humans as well as contributing positively to the environment.

References:

Haldhar SM, et al. (2021). Honeybees' diversity, pollination, entrepreneurship, and beekeeping scenario in NEH region of India. Journal of Agriculture and Ecology.



Kishan Tej M, et al. (2018). Beekeeping in India. ResearchGate.

Yigezu G, Moral MT. (2021). Honeybee keeping constraints and future prospects. Taylor & Francis.

Indian Council of Agricultural Research (2018). AICRP on Honeybee Research & Training.

National Bee Board (2023). Annual Report on Beekeeping and Honey Mission.

Khadi and Village Industries Commission (2023). Honey Mission Impact Assessment. APIS FLOAPIS

PLAY: THE FIRST CLASSROOM OF A CHILD

Article ID: AG-VO5-I12-132**Gauranga Borah***

College Of Community Science, Assam Agricultural University, Jorhat 13, India

*Corresponding Author Email ID: gaurangaborah97@gmail.com

Abstract

Play is one of the most important and crucial part of everyone's life during early childhood period. Early childhood period is regarded as one of the most essential periods for rapid growth or development as during this period the physical, cognitive, emotional, social and overall holistic development takes place. Research indicates that learning through play boosts children's academic performances, social skills and ability to manage their own behavior. However, increases in academic work load or expectations and growing use of digital tools reduces the time children get to engage in meaningful play.

Introduction

According to Maria Montessori and Friedrich Frobel work is play. Early childhood is a foundation period of overall development. The child grows in all five areas of development i.e. physical, cognitive (mental), language, social and emotional. During this period play acts as the most essential and vital role for the overall or holistic development of the child. Play not only helps a child to develop properly but also helps in inculcating good behavior, empathy, resilience etc. Before a child engage into formal schooling, their earliest learning occurs through everyday learning. Play is not a break from learning - it is learning. Play turns simple daily activities into opportunities for exploration, creativity and understanding, becoming the child's earliest and most powerful learning space. Extensive scientific research shows that play is a key catalyst for rapid brain development in early years.

Increasing screen exposure, pressure for early academic achievement, limited access to open spaces and a growing preference for structured instruction have together created a

significant “play gap”. This reduction in meaningful play opportunities affects not only children’s readiness for school but also their emotional health, creative thinking, and ability to cope with challenges. It is therefore crucial to acknowledge play as a core component of early childhood development. This article explores why play deserves to be regarded as the first classroom during early childhood and discuss ways in which society can safeguard and strengthen essential learning experience.

The Science behind play and early brain development: -

Neuroscience and developmental psychology consistently highlight that the early years are a period of extraordinary brain growth, with almost 90% of neural developing occurring before a child turns five. The 0–6-year age span is therefore considered a critical window for shaping cognitive, emotional, and social abilities. During play – whether arranging blocks, engaging in pretend activities, exploring outdoors, or singing action songs millions of neural connections are formed and reinforced.

Play stimulates both sides of the brain as: -

- The left brain, which contributes to logical thinking, language acquisition and analytical skills.
- The right brain which supports imagination, creativity, emotional expression, and visual spatial understanding.

Because of engage multiple neural networks at the same time during play, it offers a comprehensive learning experience that surpasses the effectiveness of rote or passive instruction during early childhood. Play also stimulates the release of positive neurotransmitters like dopamine, which provides motivation, improves memory and emotional wellbeing.

Major finding about play through various researches: -

Recent research from various multidisciplinary fields has consistently highlighted the developmental importance of play; -

1. **According to the American Academy of Pediatrics (2020)**, play enhances executive functioning, nurtures healthy parent–child bonding, and promotes socio-emotional competencies.
2. **Harvard University’s Center on the Developing Child** further indicate that playful interactions support the formation of neural networks involved in reasoning, problem-solving, and self-regulation.

3. **UNICEF (2018)** highlights that children learn most effectively through play-oriented approaches that encourage curiosity, perseverance, and creative exploration. Similarly, the
4. **LEGO Foundation (2023)** notes that play lays the groundwork for essential 21st-century skills such as teamwork, communication, and critical thinking.

Evidence from Indian studies, including work published in the Indian Journal of Community Medicine, shows that incorporating structured play in Anganwadi environments leads to better language skills, improved motor development, and stronger social behaviors among young children.

Taken together, these findings clearly demonstrate that play is not merely recreational—it is a fundamental biological, psychological, and educational requirement.

Benefits of Play Across Developmental Domains: -

Play contributes to a child's growth in multiple interconnected domains, shaping the mind, body and emotions simultaneously. As play influences every major area of development it serves as foundation for holistic early childhood learning. Some of the developmental areas are discuss below

1. Cognitive Development

Studies indicate that children who participate in regular play demonstrate enhanced memory, better attention control, and stronger problem-solving abilities. Play-based activities support early literacy and numeracy development and help children grasp basic concepts more effectively.

2. Social and Emotional Development

Play provides a natural context for learning social skills such as sharing, cooperation, negotiation, and conflict resolution. Imaginative play (pretend play) helps children understand and manage emotions, while group games promote teamwork and emerging leadership skills.

3. Language Development

During play, children expand their vocabulary, improve sentence structure, and refine conversational abilities. Role-play, storytelling, and interactive games expose children to new words and offer opportunities for meaningful communication.

4. Physical Development or Motor Development

Activities involving movement—such as climbing, running, and balancing—strengthen both gross and fine motor skills. Regular physical play contributes to healthy growth, lowers the risk of obesity, supports cardiovascular fitness, and boosts physical confidence.

5. Academic Readiness

Evidence shows that children in play-based early childhood programs perform better academically, display more positive classroom behavior, and demonstrate higher motivation for learning once they enter formal schooling.

NEP 2020 and its focus on play-based learning: -

The National Education Policy (NEP) 2020 places strong emphasis on play as the core of early childhood education in India. It recognizes that the age group 3 to 8 years represents a foundational stage, and that young children learn most effectively through joyful experiences rather than formal academics. The policy recommends that early education environments integrate stories, music, games, movement, outdoor play, art, hands-on activities and imaginative play, as these naturally promote language growth, brain development, creativity and social-emotional learning. NEP 2020 discourages rote teaching at this stage and encourages classrooms where children explore their surroundings, think independently, experiment with ideas and express themselves freely. By promoting activity-based and play-centered pedagogy, the policy aims to make early learning enjoyable, meaningful and developmentally appropriate, ensuring a strong base for future education and overall well-being.

The Role of Parents and Teachers in Encouraging Play: -

The value of play grows significantly when adults recognize its importance and intentionally support it. Parents and caregivers can enrich children's play experiences at home by providing a stimulating environment that includes age-appropriate play materials, open-ended resources such as clay, blocks, and crayons, opportunities for imaginative storytelling, regular outdoor exploration, and time for group interaction with peers. When parents show interest and involvement in their child's play, children feel motivated, supported and eager to explore their surroundings.

Teachers, particularly in early childhood settings, play an equally important role by designing classrooms where learning occurs naturally through exploration and hands-on activities. When educators create a play-centered atmosphere, children are encouraged to think independently, ask questions, experiment freely, and make new discoveries—key behaviors that promote

meaningful learning and holistic development. A teacher who values play creates a joyful and meaningful learning atmosphere where curiosity grows and learning happens effortlessly.

Challenges Limiting Play in Modern Childhood: -

Despite being essential for healthy development, opportunities for play in early childhood are steadily declining. Several social and lifestyle shifts have created barriers that limit a child's natural urge to explore and engage in free activities. Increased academic pressure, even in the preschool years, has pushed formal learning ahead of experiential learning. Many young children now spend long hours memorizing lessons rather than discovering concepts through songs, stories, games, and outdoor interactions.

Digital exposure is another growing concern. Easy access to mobile phones, television, and online gaming has significantly reduced outdoor play. Screen engagement tends to replace physical movement, imagination, social bonding, and sensory experiences that are crucial for early growth. Urbanization has also reduced access to open and safe play spaces, making many children confined to small indoor environments.

Changing lifestyles within families further contribute to the decline in play. Parents' busy schedules, safety concerns, and a preference for structured activities such as coaching, tuition, or skill classes leave limited time for unstructured play. In some communities, play is still viewed as a distraction from academics rather than a foundation for learning, which reduces motivation to encourage it both at home and in schools. ★ ★ ★ ★

Collectively, these challenges create a "play gap," where children miss out on opportunities that support physical fitness, emotional resilience, creativity, social skills, and cognitive development. Addressing these barriers is crucial to restoring play as an essential part of childhood and ensuring holistic development.

Conclusion

In summary, Play is the most natural and effective medium through which the foundations for cognitive, social, emotional, and physical or motor development are established and can be strengthened. When children are allowed to investigate, explore, imagine, and interact with people and their surroundings through playful experiences, they develop an understanding of both their immediate world and the broader social and cultural environment.

Early childhood is not only a period of rapid developmental expansion but also one in which growth becomes deeper and more meaningful when supported with the right

opportunities. A stimulating environment—rich in play, curiosity, and exploration—is therefore essential for nurturing a child’s potential. Recognizing play as the first classroom of life ensures that every child receives the experiences needed to become confident, creative, and capable learners throughout their lives.

References

1. Whitebread, D. (2017). The role of play in children’s development: a review of the evidence. Retrieved from: https://cms.learningthroughplay.com/media/esriqz2x/role-of-play-in-childrens-development-review_web.pdf
2. Anderson-McNamee, J. K. (n.d.). The Importance of Play in Early Childhood Development. <https://www.montana.edu/extension/health/documents/MT201003HR.pdf>
3. Severino, G. R., Cabatic, E. T., & Molina, M. M. (2024). The Role of Play in Children’s Development. retrieved from: https://www.researchgate.net/publication/389047290_The_Role_of_Play_in_Children%27s_Development
4. “The power of play: A pediatric role in enhancing development in young children.” (2018). Pediatrics, 142(3), e20182058. Retrieved from
5. “Exploring the importance of play and leisure in child-development and learning.” (2020). IJMRT.
6. Majumdar, A. (n.d.). Role of Play in Child Development. [PDF] Available at: https://www.ijtrs.com/uploaded_paper/ROLE%20OF%20PLAY%20IN%20CHILD%20DEVELOPMENT.pdf
7. “The status of early childhood development in India.” (2021). Indian Pediatrics. [PDF] Available at: <https://indianpediatrics.net/supplOct2021/S4.pdf>
8. Ginsburg, K. R., & the Committee on Communications; Committee on Psychosocial Aspects of Child and Family Health. (2007). The importance of play in promoting healthy child development and maintaining strong parent–child bonds. Pediatrics, 119(1), 182–191. <https://doi.org/10.1542/peds.2006-2697>.
9. “Operational Guidelines for Implementing Early Child Care & Development (ECD) in Public Health System.” (2018). Ministry of Health & Family Welfare, Government of India. retrieved from: <https://nirdpr.org.in/crru/docs/health/ECD%20Operational%20Guidelines%20GOI.pdf>

10. “Early Childhood Development (ECD) | UNICEF India.” UNICEF India. Retrieved from: <https://www.unicef.org/india/what-we-do/early-childhood-development>
11. “ECCE Reports.” (n.d.). NIPCCD, Government of India. retrieved from: <https://www.nipccd.nic.in/ecdce-reports>
12. “Publications – Early Childhood Development Care & Education (ECCE).” (n.d.). Ministry of Women & Child Development, Government of India. Retrieved from: <https://www.spniwcd.wcd.gov.in/ecce/archive/ecce-publications>
13. “National Early Childhood Care and Education (ECCE) Policy.” (n.d.). Government of India. [PDF]retrieved from: https://www.nitiforstates.gov.in/public-assets/Policy/policy_files/PNC503P000013.pdf
14. Banerji, R. (2024). The pre-school years in India: Progress since NEP 2020. [PDF] Available at: https://asercentre.org/wp-content/uploads/2022/12/The-pre-school-years-in-India_Progress-since-NEP-2020_Rukmini-Banerji.pdf
15. Harvard University Center on the Developing Child. (2015) . *How early experiences shape the developing brain*.
16. Lillard, A. S., Lerner, M. D., Hopkins, E. J., Dore, R. A., Smith, E. D., & Palmquist, C. M. (2013). The impact of pretend play on children’s development: A review of the evidence. *Psychological Bulletin*, 139(1), 1–34. <https://doi.org/10.1037/a0029321>
17. Awopetu, A. V. (2024). The significance of play in promoting child development and strong parent-child bonds. retrieved from : <https://www.idpublications.org/wp-content/uploads/2024/06/Full-Paper-THE-SIGNIFICANCE-OF-PLAY-IN-PROMOTING-CHILD-DEVELOPMENT-AND-STRONG-PARENT-CHILD-BONDS.pdf>
18. Mauro, A. (2024). The impact of play-based learning on early childhood education. Retrieved from: <https://digitalcommons.cortland.edu/cgi/viewcontent.cgi?article=1185&context=theses>
19. World Health Organization. (2019). Guidelines on physical activity, sedentary behavior and sleep for children under 5 years of age.
20. Hirsh-Pasek, K., Golinkoff, R. M., Berk, L., & Singer, D. (2009). A mandate for playful learning in preschool: Presenting the evidence. Oxford University Press. (book / evidence review).

Volume: 05 Issue No: 12

MOLECULAR MECHANISMS OF GENOME PACKAGING IN PLANT VIRUSES AND TRANSLATIONAL APPLICATIONS IN AGRICULTURAL BIOTECHNOLOGY

Article ID: AG-V05-I12-133

**Tushar Ranjan^{1*}, Ravi Ranjan Kumar², Kumari Rajani², Sanskriti Kumari¹ and
Mohammad Ansar³**

¹Dept. of Molecular Biology & Genetic Engineering, Bihar Agricultural University, Sabour

²Bhola Paswan Shastri Agricultural College, Purnea (BAU, Sabour)

³ICAR-Central Institute of Temperate Horticulture, Srinagar, India

*Corresponding Author Email ID: mail2tusharranjan@gmail.com

Abstract

The process of viral genome packaging represents a paradigm of macromolecular assembly efficiency and specificity. In plant viruses, this process is governed by precise interactions between capsid proteins (CP), viral nucleic acids, and often, virus-encoded ATPase motor proteins. This article details the mechanistic biology of plant virus genome encapsidation, with particular emphasis on the ATP-dependent packaging systems, and explores the emerging applications of these principles in developing next-generation agricultural biotechnologies, including targeted delivery systems, transient expression platforms, and diagnostic tools.

Keywords: Genome packaging, plant virus, ATP, capsid protein

Introduction

Genome encapsidation is a critical step in the viral life cycle, determining virion stability, infectivity, and host interactions. Plant viruses have evolved diverse strategies to achieve this, broadly categorized by their dependence on enzymatic energy (Ranjan et al., 2023). The provided schematic illustrates key mechanistic distinctions: Type I systems utilize a dedicated ATPase motor for processive, directional packaging initiated at a specific *pac* (packaging) site, whereas other systems may rely on co-assembly or other energy-independent mechanisms (Mohanty et al., 2023). Understanding these molecular machines at a high resolution provides a foundational toolkit for bioengineering.

Mechanistic Insights into ATP-Dependent Genome Packaging :

The canonical model, exemplified by certain viruses within the *Alphaflexiviridae* and other families, involves a highly ordered sequence of events. Initial recognition is mediated by the specific binding of capsid protein (CP) or a packaging-associated protein to a *cis*-acting nucleotide sequence, the **Pac site**. This binding event nucleates the assembly of an oligomeric complex, often involving an **ATPase** of the AAA+ family (Type IC in the schematic). The functional and evolutionary significance of this ATPase fold in packaging has been a key area of recent research (Ranjan et al., 2021). This ATPase functions as a molecular motor; hydrolysis of ATP to ADP + Pi provides the conformational energy required to translocate the viral genome through a central pore or channel in the growing procapsid structure (Fig. 1). This processive, energy-driven mechanism ensures high-fidelity packaging of a complete genome per virion, minimizing the production of non-infectious particles. Direct experimental evidence for this mechanism comes from studies such as those on *Potato leafroll virus* (PLRV), where knockdown of the capsid protein's ATPase domain was shown to explicitly inhibit genome packaging (Kumar et al., 2022). The schematic contrasts this with less precise, entropy-driven co-assembly pathways (Type IB), where CP subunits polymerize around the nucleic acid without directed motor activity, often resulting in heterogeneous particle populations—a topic of ongoing debate regarding energy requirements (Mohanty et al., 2023).

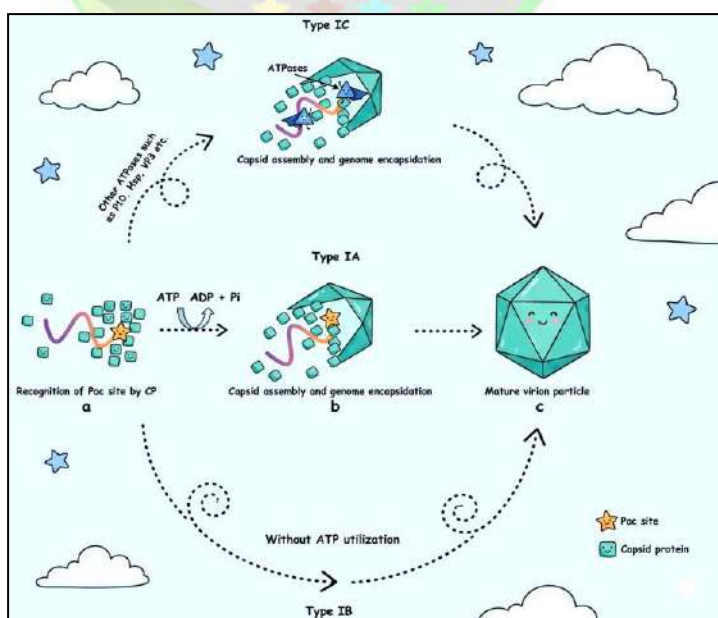


Fig. 1: A cartoon image of assembly process of plant virus

Virus-Like Particles (VLPs) as Programmable Nanoplatforams for Agricultural Biotechnology :

The precise self-assembly properties of viral CPs, honed through evolutionary processes that often involve generalist host interactions (Kumar et al., 2020), enable the production of **Virus-Like Particles (VLPs)**. These are supramolecular structures that maintain the native capsid architecture but lack the viral genome. From a bioengineering perspective, VLPs are structurally defined, monodisperse nanocontainers with modifiable interior and exterior surfaces. Their relevance to agricultural science is multi-fold.

The interior cavity of VLPs can be loaded with bioactive compounds via encapsulation strategies (e.g., diffusion, disassembly/reassembly, or pore-mediated loading). Functionalization of the VLP exterior with peptides or chemical ligands can enable tissue-specific or cellular targeting. This allows for the precise delivery of nutrients (e.g., micronutrients), pesticides (e.g., RNAi triggers), or signaling molecules (e.g., plant defense elicitors) directly to the phloem, rhizosphere, or intracellular compartments, drastically increasing uptake efficiency and reducing environmental runoff. The principles of such targeted delivery are informed by viral movement mechanisms, where inhibiting systemic translocation—as demonstrated by siRNA constructs against viral movement proteins (Kumari et al., 2020)—highlights the critical checkpoints that can be co-opted or bypassed for beneficial delivery.

Plant viral vectors have long been used for transient protein expression. Modern iterations leverage the packaging signals and CP functions to create **replicon-based delivery systems**. These engineered "deconstructed" viruses can deliver RNA replicons encoding CRISPR-Cas nucleases, guide RNAs, or beneficial trait genes. The key advantage is high-level, transient expression in somatic tissues without genomic integration, accelerating functional genomics and non-transgenic trait testing. Systems based on *Tobacco mosaic virus* (TMV) and *Potato virus X* (PVX) are prominent examples. Furthermore, the highly ordered, repetitive surface of VLPs is ideal for epitope presentation. In agriculture, this can be utilized to develop vaccines for livestock by displaying antigens from pathogenic viruses or bacteria. Moreover, VLPs can serve as multivalent capture agents in diagnostic assays. Conjugating VLPs with antibodies or DNA probes enhances detection sensitivity for plant pathogens in field-deployable lateral flow or ELISA formats due to the high signal density per binding event.

Challenges and Future Research Directions :

While the potential is significant, translational applications face several technical and regulatory hurdles. **Stability and Scalability:** VLP integrity and cargo retention under field conditions (UV, temperature, rainfastness) must be optimized. Large-scale, cost-effective production in plant or microbial expression systems is an active area of process engineering. **Delivery Efficiency:** Overcoming the plant cell wall and reaching the appropriate cellular compartment remains a challenge, often requiring fusion to cell-penetrating peptides or exploitation of natural viral movement protein functions, the inhibition of which has been a successful antiviral strategy (Kumari et al., 2020). **Regulatory Pathways:** The classification of VLP-based bioactive deliveries—as a plant-incorporated protectant, a biochemical pesticide, or a novel entity—will require clear regulatory science and risk-assessment frameworks informed by a deep understanding of virus-host co-evolution (Kumar et al., 2020).

Conclusion

The study of genome packaging in plant viruses, as detailed in recent reviews (Ranjan et al., 2023), has transcended fundamental virology to inform a disruptive technological frontier. The principles of specific nucleic acid recognition, ATP-fueled molecular transport (Kumar et al., 2022; Ranjan et al., 2021), and programmed self-assembly are being repurposed to create smart delivery nanocarriers and expression vectors. For the agricultural scientist, these systems offer a new paradigm of intervention: moving from whole-organism or field-scale applications to precise, cellular-scale engineering. Continued research into the structural virology of diverse plant virus families will expand the available toolkit, while interdisciplinary collaboration between virologists, nanotechnologists, and plant physiologists is essential to solve the remaining delivery and production challenges, ultimately paving the way for more sustainable and precise crop protection and enhancement strategies.

References

- Ranjan, T., Ranjan Kumar, R., Ansar, M., Kumar, J., Mohanty, A., Kumari, A., ... & Ahmad, M. F. (2023). The curious case of genome packaging and assembly in RNA viruses infecting plants. *Frontiers in Genetics*, 14, 1198647.
- Mohanty, A., Kumar, J., Ranjan, T., Kumar, R. R., & Rajani, K. (2023). Is genome packaging in small plant viruses energy independent?. *JAPS: Journal of Animal & Plant Sciences*, 33(1).

- Kumar, J., Kumar, R. R., Das, D. K., Mohanty, A., Rajani, K., Kumari, N., ... & Ranjan, T. (2022). Knockdown of capsid protein encoding novel ATPase domain inhibits genome packaging in potato leafroll virus. *3 Biotech*, 12(3), 66.
- Ranjan, T., Pal, A. K., Prasad, B. D., Kumar, R. R., Kumar, M., Shamim, M., & Jambhulkar, S. (2021). Reassessing the mechanism of genome packaging in plant viruses with lessons from ATPase fold. *Australasian Plant Pathology*, 50(3), 253-266.
- Kumari, P., Kumar, J., Kumar, R. R., Ansar, M., Rajani, K., Kumar, S., & Ranjan, T. (2020). Inhibition of potato leafroll virus multiplication and systemic translocation by siRNA constructs against putative ATPase fold of movement protein. *Scientific reports*, 10(1), 22016.
- Kumar, M., Bharti, R., & Ranjan, T. (2020). The evolutionary significance of generalist viruses with special emphasis on plant viruses and their hosts. *Open Virol J*, 14, 22-29.

Volume: 05 Issue No: 12

TRANSGENIC CHICKENS ENCOMPASS ADVANCED METHODS, STRATEGIC APPLICATIONS AND EMERGING FRONTIERS IN AVIAN BIOTECHNOLOGY.

Article ID: AG-VO5-I12-134**N. Kowsalya¹, G. Karthikeyan² and K. S. Sreyass³**

¹Assistant professor, Poultry technology, College of Poultry Production and Management, Tamil Nadu veterinary and Animal Sciences University

²Assistant professor, veterinary science, SRM college of Agricultural sciences, SRM University

³Assistant professor, veterinary science, SRM college of Agricultural sciences, SRM University, Tamil Nadu, India

*Corresponding Author Email ID: nkowsalya231299@gmail.com

Introduction

The genetic engineering of chickens has advanced from a conceptual possibility in the late twentieth century to a practical and increasingly refined research platform. Historically, the avian reproductive system presented significant obstacles to targeted genome modification. Unlike mammals, a chicken embryo is already at the gastrula stage at the moment the egg is laid, complicating early access to pluripotent cells. In addition, the unique structure of the egg, the timing of embryonic development and limited initial knowledge of avian germline biology posed substantial challenges. Yet, over the past three decades, steady improvements in germline cell culture, gene-delivery strategies and genome-editing systems have transformed what can be achieved in poultry biotechnology.

Transgenic chickens now serve roles that extend far beyond traditional breeding objectives. They are being developed as models for immunology, virology and developmental biology; as disease-resistant poultry lines for agricultural use; and as bioreactors capable of producing complex therapeutic proteins within their eggs. Although commercial deployment remains limited, the scientific foundation is maturing rapidly, offering realistic prospects for broader application within the next decade. The progress in avian transgenesis has been

supported by earlier foundational methods for gene transfer including viral vectors, somatic cell fusion, chromosome-mediated transfer and microinjection

Foundations of Gene Transfer and Early Avian Transgenesis

Understanding modern methods requires recognizing the scientific groundwork established in earlier decades. There are several classical gene-transfer mechanisms: somatic cell fusion, chromosome-mediated transfer and direct gene insertion into embryos. Somatic cell fusion, triggered through inactivated Sendai virus or polyethylene glycol, enables hybrid cells to proliferate and helps map genes to chromosomes. Chromosome-mediated transfer absorbs isolated chromosome fragments into host cells during metaphase arrest, facilitating movement of genetic material across breeds and species. The requirements for successful gene transfer: locating the gene of interest, removing it with appropriate regulatory elements, inserting it into a vector and integrating it into the host genome. Integration typically occurs at a single chromosomal site, producing hemizygous founders whose offspring inherit the transgene in predictable Mendelian ratios. These early concepts underpin all subsequent developments in avian biotechnology.

For non-viral gene transfer, methods such as calcium phosphate coprecipitation, DEAE-dextran transfection, lipofection, electroporation, protoplast fusion, and microinjection. Although initially optimized for mammalian cells, they informed the early attempts to introduce exogenous DNA into avian embryos. However, because avian embryos are more developed at oviposition, direct microinjection into the pronucleus, a mainstay of mammalian transgenesis was only partially transferrable.

Approaches to Generating Transgenic Chickens

Viral Vector–Based Methods

Among the first practical methods for engineering chickens were viral vector systems, especially retroviral and lentiviral vectors. These viruses integrate their genetic cargo into the genome of early blastodermal cells, enabling a proportion of the resulting germline to carry the transgene. replication-competent and replication-deficient retroviruses were employed to generate chickens resistant to specific avian leukosis viruses. Despite their historical importance, viral vectors have inherent limitations. Integration sites cannot be predetermined, leading to variable expression and copy numbers differ among individuals. The chromatin environment

surrounding the insertion site can also influence transcription. Yet these systems provided crucial proof-of-concept demonstrations that stable germline transmission was possible in birds.

Primordial Germ Cell Manipulation

The isolation, culture and genetic modification of primordial germ cells (PGCs) represent one of the most transformative breakthroughs in avian biotechnology. PGCs, once isolated, can be expanded in vitro for extended periods without losing their capacity to contribute to the germline. They can be genetically edited, clonally expanded, screened for correct modifications and reintroduced into host embryos. When injected into sterile or partially sterilized embryos, the introduced PGCs colonize the gonads and give rise to gametes. This method provides a level of control that earlier viral approaches lacked. Mosaicism is reduced because only verified clones are introduced. Off-target mutations can be screened and eliminated prior to embryo injection. As a result, transgenic lines generated through PGC manipulation exhibit more predictable inheritance patterns, more consistent expression, and improved biosafety.

Genome Editing Using CRISPR–Cas Systems

The introduction of CRISPR-Cas9 into avian biology ushered in an era of precision genome engineering. In chickens, the technique is primarily applied through PGC modification, although direct embryo editing has also been demonstrated. CRISPR enables precise gene knockouts, targeted knock-ins and single-nucleotide substitutions. One challenge in avian CRISPR editing is the relatively low efficiency of homology-directed repair (HDR), as embryos preferentially employ non-homologous end joining (NHEJ). Researchers have improved HDR by optimizing donor templates, altering timing of delivery, or using CRISPR-Cas12a, base editors, and prime editors, which reduce reliance on double-stranded breaks. As these tools mature, engineering multigenic traits such as comprehensive disease resistance or enhanced nutrient composition becomes increasingly feasible.

Transposon-Based Delivery Tools

Transposons such as piggyBac and Sleeping Beauty offer an additional strategy for stable genomic integration. Capable of carrying larger genetic payloads than viral vectors, transposons integrate preferentially into transcriptionally active regions, supporting strong and consistent expression. When combined with PGC manipulation, transposon-mediated transgenesis allows researchers to screen multiple integration events and select clones exhibiting optimal expression

profiles. This is particularly relevant for producing high-yield bioreactor chickens where consistent protein secretion is essential.

Scientific and Practical Applications

Chickens as Bioreactors for Therapeutic Protein Production

Among all applications of transgenic poultry, the production of therapeutic proteins in eggs is the most commercially advanced. A laying hen produces more than 250 eggs per year, each containing substantial quantities of protein-rich albumen. By driving transgene expression using oviduct-specific promoters, recombinant proteins can be secreted into egg white at concentrations capable of meeting industrial production requirements. This system offers biological and economic advantages. Avian cells perform many human-compatible post-translational modifications, making proteins produced in eggs suitable for therapeutic use. Human interferons, growth factors, and monoclonal antibodies have been successfully produced in this manner. Although regulatory pathways remain rigorous, several biotechnology companies now maintain transgenic chicken platforms for pharmaceutical development.

Engineering Disease Resistance

Infectious diseases impose substantial global economic losses in poultry production. Genetic engineering provides a promising avenue for developing disease-resistant chickens through targeted editing of host genes essential for viral replication, insertion of antiviral RNA interference constructs, or modulation of innate immune pathways. The viral resistance through transgenic insertion, such as chickens carrying ALV6 components resistant to specific avian leukosis subgroups. Although laboratory outcomes are promising, translation to commercial poultry lines requires assessment of performance traits, long-term stability, welfare considerations and consumer acceptance.

Modifying Growth, Physiology and Product Composition

Efforts to enhance growth rate or feed conversion efficiency via genetic modification remain experimental and controversial. For example, manipulation of the myostatin (MSTN) gene can increase muscle mass, but potential welfare concerns and metabolic side-effects must be carefully evaluated. Other research aims to modify egg composition, altering lipid profiles, reducing allergens, or enriching vitamins and antioxidants. These studies demonstrate the feasibility of nutritional engineering but still face uncertain commercial pathways.

Humanized Antibody Production

The avian immune system provides unique opportunities for generating therapeutic antibodies. Introducing human immunoglobulin segments into the chicken genome allows the production of antibodies structurally similar to human counterparts while benefiting from the extensive diversification mechanisms inherent to avian B-cell biology. Such chickens can serve as efficient platforms for antibody discovery, with eggs offering a non-invasive route for collection.

Use in Fundamental Biological Research

Beyond industrial applications, transgenic chickens are indispensable for basic biological research. Fluorescent reporter lines allow the visualization of developmental processes. Gene knockouts facilitate the study of metabolism, immunity, and host–pathogen interactions. External embryonic development makes chickens a valuable system for live imaging and experimental manipulation.

Technological Developments Supporting Progress

Several technical innovations have enabled the rapid evolution of avian transgenic methods. Refined promoters and expression systems allow tissue-specific or stage-specific gene regulation, reducing off-target effects and improving bioreactor yields. Advances in embryo handling, including improved micromanipulation tools, windowing techniques and surrogate eggshell culture have enhanced embryo survival after intervention. Germline-ablation strategies now allow nearly complete replacement of host germ cells with modified PGCs, dramatically increasing transmission efficiency and reducing breeding cycles.

Limitations and Ethical Considerations

The inherent limitations of transgenic poultry, including longer generation intervals compared to small laboratory animals and ethical concerns surrounding DNA hybridization and consumer perception. Although these constraints are real, they have not halted progress. Safety concerns, especially regarding viral vectors and potential off-target editing, must continue to be addressed. Public acceptance remains a critical factor, requiring transparency, rigorous testing and ethical stewardship.

Conclusion

Transgenic chicken technology has progressed from a scientific aspiration into an increasingly robust set of methodologies grounded in cellular biology, developmental science and gene-editing advances. The convergence of PGC culture, CRISPR-based genome editing and



refined gene-delivery systems has dramatically expanded the possibilities for engineering stable and precisely modified poultry lines. While bioreactor applications for therapeutic protein production are currently the most advanced, the broader scientific and agricultural potential is immense, encompassing disease resistance, developmental biology, immunology and food innovation. Significant challenges remain, including regulatory oversight, public acceptance and long-term welfare considerations. Nevertheless, the trajectory of research suggests that transgenic chickens will play an expanding and influential role in biotechnology and poultry science in the coming decades.

Volume: 05 Issue No: 12

MECHANISTIC INSIGHTS INTO BIOSTIMULANT-MEDIATED PLANT-MICROBE FEEDBACKS

Article ID: AG-VO5-I12-135**Gokila. B, Pramila. P* and Parameswari C**

Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University,
Coimbatore - 641 003, Tamil Nadu, India

*Corresponding Author Email ID: gokilasingh@gmail.com

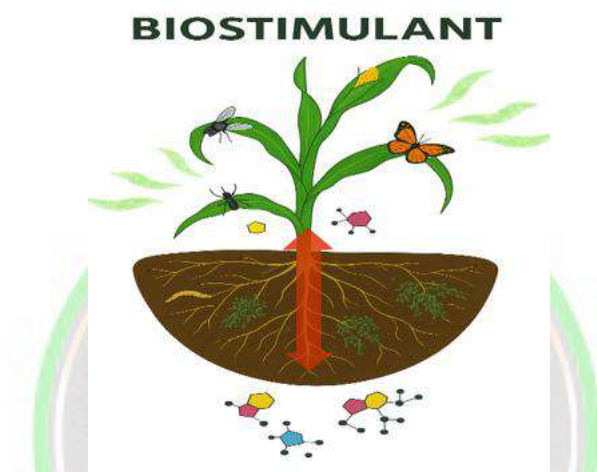
Abstract

Climate change is disrupting agriculture by altering temperature and rainfall patterns, reducing soil nutrient availability and crop productivity. Plant biostimulants naturally derived substances that enhance plant performance without acting as fertilisers or pesticides offer a sustainable strategy to improve nutrient-use efficiency. Key types include humic substances, seaweed extracts, chitosan, beneficial inorganic compounds, and microbial inoculants such as PGPR and mycorrhizae. These inputs enhance nutrient uptake, root activity, soil structure, and stress tolerance. Although biostimulants improve growth, yield, and resilience, adoption remains limited due to low awareness and incomplete mechanistic understanding. Further research and optimised formulations are essential for climate-resilient agriculture

Introduction

Climate change, driven by human activities that release large amounts of greenhouse gases into the atmosphere, is posing serious challenges to global agriculture (Elbasiouny et al., 2020). Rising temperatures and changing rainfall patterns are reducing soil nutrient availability and crop yields. To secure food for a growing population, it has become essential to improve how efficiently crops absorb and use nutrients. Finding sustainable solutions is now a key priority for the future of farming (Kakani et al., 2020). One such approach gaining attention is the use of plant biostimulants. These are special products made from natural or biological substances that are not fertilisers, pesticides, or soil conditioners but can still boost plant performance. They help crops use nutrients more efficiently, tolerate stress caused by drought or

heat, and improve yield and quality. Biostimulants are generally grouped into three types based on their sources: humic substances (HS), hormone-containing products (HCP), and amino acid-containing products (AACP). For example, HCPs such as seaweed extracts contain natural plant hormones like auxins and cytokinins, which stimulate growth and development (Kauffman et al., 2007). According to Compant et al. (2019), microbes including archaea, bacteria, and fungi form a diverse group of organisms that coexist with plants, collectively referred to as the plant microbiota.



Rhizosphere-associated microbes can perceive and interpret signals produced by themselves, other microbes, or the plant host, thereby influencing plant physiology through the release of signalling molecules. These molecular interactions play a vital role in inducing plant immunity, enhancing stress tolerance, and promoting overall plant growth, health, and nutrition, as well as shaping the rhizosphere microbiome. Examples of such signalling molecules include N-acyl homoserine lactones (AHLs), diffusible signal factors, diketopiperazines, phytohormone-like compounds, and volatile organic compounds.

Types of Plant Biostimulants

The major categories of plant biostimulants comprise substances and microorganisms, including beneficial bacteria (mainly plant growth-promoting rhizobacteria; PGPRs) and fungi. These microorganisms may exist freely in the soil, be rhizospheric, or form endosymbiotic associations (Halpern et al., 2015). The following substances and microbial groups are widely utilised in agriculture:

a) Humic Substances (HS): Humic substances are natural constituents of soil organic matter, formed through the decomposition of plant, animal, and microbial residues, as well as the metabolic activity of soil microorganisms utilising these substrates. HS are heterogeneous compounds classified according to molecular weight and solubility into humic acid, fulvic acid, and humin. These compounds participate in complex dynamic processes of association and dissociation into supramolecular colloids, which are influenced by plant root exudates and proton release. HS enhance the uptake of macro- and micronutrients by increasing the cation exchange capacity (CEC) of soil. The polyanionic nature of HS also promotes phosphorus availability by preventing calcium phosphate precipitation. Furthermore, HS stimulate root plasma membrane H^+ -ATPase activity, which converts the free energy from ATP hydrolysis into an electrochemical gradient used for the active transport of nitrate and other nutrients.

b) Seaweed Extracts: Seaweed extracts are applied to soil and plants through hydroponic systems or foliar sprays. Purified seaweed-derived compounds such as polysaccharides (laminarin, alginates, and carrageenans) and their breakdown products are also used. These extracts provide essential micro- and macronutrients, sterols, nitrogen-containing compounds (e.g., betaines), and phytohormones. The most commonly used seaweeds belong to the brown algae genera *Ascophyllum*, *Fucus*, and *Laminaria*, while carrageenans originate from red seaweeds, representing a distinct phylogenetic lineage. The polysaccharides in seaweed derivatives contribute to gel formation, improving water retention and soil aeration. Their polyanionic compounds facilitate ion fixation and cation exchange, which can enhance heavy metal retention for soil remediation. Additionally, seaweed extracts contain protective bioactive compounds, including antioxidants and regulators of stress-responsive genes, which impart anti-stress effects and enhance plant resilience.

c). Chitosan: Chitosan is a deacetylated derivative of the biopolymer chitin, produced naturally or through industrial processes. In plants, chitosan oligomers act as defence elicitors, triggering the activation of defence-related genes. In agricultural applications, chitosan is widely used for protecting crops against fungal pathogens and mitigating abiotic stresses such as drought, salinity, and cold. Its mode of action includes inducing stomatal closure through an abscisic acid (ABA)-dependent mechanism, thereby enhancing stress tolerance. Similarly, laminarin a storage β -glucan derived from brown algae has also been employed in agriculture for its elicitor properties and role in plant defence activation.

d). Inorganic compounds: Mineral elements such as aluminium (Al), cobalt (Co), sodium (Na), selenium (Se), and silicon (Si) are considered beneficial to plants and are naturally available in soils, for example, as amorphous silica in graminaceous species. These elements contribute to strengthening cell walls through silica deposition and play protective roles under various stress conditions, such as pathogen attack (Se) and osmotic stress (Na). Additionally, some essential compounds including chlorides, phosphates, phosphides, silicates, and carbonates have been used as fungicides due to their influence on osmotic balance, pH regulation, redox homeostasis, hormone signalling, and enzyme activities (*e.g.* peroxidase) associated with stress responses. According to Pilon-Smits et al. (2009), such beneficial elements can enhance plant growth and improve the quality of plant products under abiotic stress conditions.

e). Beneficial fungi and bacteria: Since evolutionary times, the mutualism–parasitism continuum has shaped the co-evolution of plants and fungi. Mycorrhizal fungi, a heterogeneous group, form symbiotic associations with more than 90% of all plant species. In the context of sustainable agriculture, the utilisation of mycorrhiza has demonstrated multiple benefits, including enhanced nutrient-use efficiency (particularly phosphorus mobilisation), improved tolerance to biotic and abiotic stresses, and better regulation of plant–water relations. Recent studies reveal that fungal hyphal networks not only interconnect plants but also influence rhizosphere signalling processes, thereby modifying microbial community structure and nutrient dynamics. Arbuscular mycorrhizal fungi (AMF) often establish tripartite associations with plants and rhizobacteria; however, large-scale propagation of AMF remains challenging due to their obligate biotrophic nature. Other fungal endophytes, such as *Trichoderma* spp. (*Ascomycota*), also colonise plant roots and contribute to nutrient mobilisation.

In addition, the biotechnological exploitation of *Trichoderma* spp. has gained considerable attention, as these fungi function both as biopesticidal (mycoparasitic) and biocontrol agents through the induction of plant disease resistance. Bacteria establish associations with plants at various spatial scales, ranging from the surrounding soil to the root surface and even internal plant tissues; these zones are commonly referred to as the rhizosphere and rhizoplane. In agricultural applications, bacterial biostimulants are broadly categorised into two groups: endosymbionts and rhizosphere-dwelling plant growth-promoting rhizobacteria (PGPR), the latter often commercialised as biofertilisers. Owing to the taxonomic and functional diversity of PGPR (*Arthrobacter* spp., *Enterobacter* spp., *Acinetobacter* spp., *Pseudomonas* spp.,

Ochrobactrum spp., *Bacillus* spp., and *Rhodococcus* spp.), plant responses can vary considerably, and challenges in inoculant formulation frequently lead to inconsistent field performance. Nevertheless, the global market for bacterial biostimulants continues to expand, and PGPR-based products are increasingly viewed as “plant probiotics” due to their contributions to plant nutrition and immune regulation (Berendsen et al., 2012). Table 1 showed the source of biostimulants and its activity on plant health.

Table 1. Effect of different bio-stimulants and its activity (Drobek et al., 2019)

Source of Biostimulant	Activity
Enzymatic or chemical hydrolysates of vegetable and animal wastes (e.g., bone meal, casein, collagen)	✓ Enhance nutrient (N & P) uptake and translocation ✓ Improve yield and grain quality in cereals ✓ Provide protection against biotic and abiotic stresses ✓ Support soil health through rhizosphere modulation and improved microbial diversity
Anaerobic digestion products from plant, animal, and lignin-based biomass	✓ Exhibit auxin-like effects ✓ Improve nutrient availability and uptake
Marine algal biopreparations (<i>Ascophyllum nodosum</i> , <i>Sargassum wightii</i> , <i>Ecklonia maxima</i> , <i>Enteromorpha intestinalis</i> , <i>Gelidium pectinatum</i>)	✓ Scavenge free radicals through high antioxidant potential ✓ Provide chelating effects and enhance resistance to biotic and abiotic stresses ✓ Improve fruit shelf-life and thermal tolerance ✓ Protect plants against drought stress
Beneficial fungi (<i>Rhizophagus intraradices</i> , <i>Rhymbocarpus aggregatus</i> , <i>Glomus</i> spp., <i>Trichoderma</i> spp., <i>Heteroconium chaetospora</i>)	✓ Promote plant growth and yield, including synergistic interactions with beneficial bacteria (e.g., <i>Azotobacter</i> spp.) ✓ Protect plants against oxidative stress

Conclusion

Biostimulants hold significant potential for enhancing plant cultivation, yet their integration into conventional farming remains limited, largely due to insufficient farmer awareness regarding their functions and appropriate application. Wider adoption of commercial biostimulants could reduce reliance on chemical fertilisers and, in turn, help mitigate environmental degradation. Their demonstrated benefits including improved plant health through enhanced antioxidant activity, better crop quality, enriched soil health, and support for biodiversity underscore their value in sustainable agriculture. Nevertheless, the specific mechanisms underlying their effects require further elucidation. Advancing climate-resilient and sustainable agricultural systems will depend on continued, rigorous research into the development, optimisation, and field-level performance of biostimulants.

References

- Kauffman, G.L., Kneivel, D.P., Watschke, T.L., 2007. Effects of a biostimulant on the heat tolerance associated with photosynthetic capacity, membrane thermostability, and polyphenol production of perennial ryegrass. *Crop Sci.* 47,261–267
- V. Kakani, V.H. Nguyen, B.P. Kumar, H. Kim, V.R. Pasupuleti. 2020. A critical review on computer vision and artificial intelligence in food industry. *J. Agric. Food Res.*, 2.
- H. Elbasiouny, B.A. Elbanna, E. Al-Najoli, A. Alsherief, S. Negm, E. Abou El-Nour, A. Nofal, S. Sharabash. 2020. Agricultural waste management for climate change mitigation: some implications to Egypt, *Waste Manage. MENA Regions (2020)*, pp. 149-169
- M. Drobek, M. Frac and J.Cybulska. 2019. Plant Biostimulants: Importance of the Quality and Yield of Horticultural Crops and the Improvement of Plant Tolerance to Abiotic Stress—A Review. *Agronomy* 2019, 9, 335
- R.L Berendsen, C.M.J Pieterse, P.A.H.M Bakker. 2012 The rhizosphere microbiome and plant health. *Trends Plant Sci.* 17(8):478-86.
- Elizabeth A H Pilon-Smits, Colin F Quinn, Wiebke Tapken, Mario Malagoli, Michela Schiavon. 2009. Physiological functions of beneficial elements. *Curr Opin Plant Biol.* 12.(3):267-74.
- S. Compant, A. Samad, H. Faist, A. Sessitsch. 2019. A review on the plant microbiome: Ecology, functions, and emerging trends in microbial application. *Journal of Advanced Research.* 19.29-37.

HIGH THROUGHPUT PHENOTYPING IN AGRICULTURE: A TOOL FOR ACCELERATING CROP IMPROVEMENT

Article ID: AG-VO5-I12-136

Barish Patel^{*1}, M. B. Parmar², P. M. Sondarava¹, R. L. Ghetiya³ and Lalita Kumari¹

¹ Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat), India - 388110

² Main Rice Research Station, Anand Agricultural University, Nawagam (Gujarat), India – 387540

¹ Department of Agricultural Statistics, B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat), India - 388110

*Corresponding Author Email ID: barish3011@gmail.com

Abstract

Rapid advances in genomics have revolutionized crop improvement; however, progress in genetic gain is often constrained by the lack of precise, large-scale phenotypic data. High Throughput Phenotyping (HTP) has emerged as a transformative approach to bridge the genotype-phenotype gap by enabling fast, accurate, non-destructive and multidimensional measurement of plant traits. HTP integrates sensor technologies, imaging systems, automation, robotics and data analytics to quantify morphological, physiological and biochemical traits at multiple spatial and temporal scales. This review discusses the principles, platforms and sensors used in high throughput phenotyping, highlights its role in plant breeding, precision agriculture and genomics-assisted selection.

Keywords: High throughput phenotyping, Phenomics, Crop improvement, Remote sensing, Plant breeding, Precision agriculture

1. Introduction

Global agriculture faces unprecedented challenges due to population growth, climate change, shrinking natural resources and evolving stresses. It is estimated that global food production must increase significantly to feed nearly 10 billion people by 2050. While advances

in next-generation sequencing have enabled rapid and cost-effective genotyping, the utilization of genomic information in breeding programs remains limited by the lack of high-quality phenotypic data. This imbalance has resulted in the widely recognized genotype-phenotype gap.

Phenotyping, traditionally conducted through manual and destructive methods, is labour-intensive, time-consuming and often subject to environmental bias. High Throughput Phenotyping (HTP) addresses these limitations by enabling automated, non-invasive and repeated measurement of complex plant traits under controlled and field conditions. Consequently, HTP has become a cornerstone of modern crop improvement programs.

2. Concept of High Throughput Phenotyping and Phenomics

High Throughput Phenotyping refers to the rapid and precise acquisition of multidimensional phenotypic data from plants using advanced sensing technologies and automated platforms. It encompasses measurements at different organizational levels, ranging from cells and organs to whole plants and crop canopies.

Phenomics, a closely related concept, is defined as the large-scale study of phenotypes and their interaction with genotype and environment. It integrates plant physiology, genetics, engineering, bioinformatics and data science to enable holistic understanding of plant performance across environments. Both forward phenomics (phenotype-to-gene) and reverse phenomics (gene-to-phenotype) approaches are widely employed in crop research.

3. Components of High Throughput Phenotyping Systems

An HTP system typically consists of the following components:

3.1 Sensors and Imaging Technologies

HTP relies on diverse sensors that capture plant traits based on interaction with electromagnetic radiation or physical signals.

- **RGB Imaging:** Used for measuring morphological traits such as plant height, canopy cover, biomass, leaf area and growth dynamics.
- **Thermal Imaging:** Detects canopy temperature to assess plant water status, transpiration and drought stress.
- **Fluorescence Imaging:** Measures chlorophyll fluorescence to evaluate photosynthetic efficiency and early stress responses.
- **Multispectral and Hyperspectral Imaging:** Captures reflectance across multiple wavelengths, enabling estimation of pigment composition, nutrient status, disease

severity and vegetation indices.

- **Depth Sensors and LiDAR:** Used to quantify three-dimensional plant architecture, plant height and canopy structure.



Figure 1. Components of High Throughput Phenotyping

3.2 Phenotyping Platforms

HTP platforms are classified based on deployment environment:

- **Controlled Environment Platforms:** Growth chambers and greenhouses equipped with conveyor belts, robotic arms and fixed sensors.
- **Ground-Based Platforms:** Phenocarts, tractor-mounted systems and field gantries.
- **Aerial Platforms:** Unmanned Aerial Vehicles (UAVs) and drones for rapid assessment of large breeding populations.
- **Satellite-Based Platforms:** Enable large-scale monitoring but with lower spatial resolution.

3.3 Data Processing and Management

HTP generates massive datasets requiring advanced image processing, feature extraction and statistical modelling. Machine learning and artificial intelligence are increasingly used for trait prediction, disease detection and stress classification. Robust database systems and data-sharing platforms are essential for efficient utilization of phenotypic information.

4. Applications of High Throughput Phenotyping

4.1 Plant Breeding and Genetic Gain

HTP enhances selection accuracy by enabling evaluation of large populations with high precision. It allows dynamic phenotyping across developmental stages and environments,

thereby improving selection for complex traits such as yield stability, drought tolerance and disease resistance. Integration of HTP with genomic selection and GWAS accelerates breeding cycles and genetic gain.

4.2 Integration with Genomics and GWAS

High-resolution phenotypic data generated through HTP have significantly improved the power of genome-wide association studies. Traits such as canopy temperature, spectral indices, lodging resistance and disease severity have been successfully mapped to QTLs and candidate genes in crops like rice, wheat, maize and soybean.

4.3 Precision Agriculture

HTP supports site-specific crop management by enabling real-time detection of nutrient deficiencies, water stress, weeds and diseases. These insights facilitate precision input application, reduce resource wastage and enhance sustainability.

4.4 Stress Detection and Crop Monitoring

HTP enables early detection of biotic and abiotic stresses before visual symptoms appear. This is particularly valuable for screening large germplasm collections under drought, heat, salinity and disease pressure.

5. Challenges in High Throughput Phenotyping

Despite its potential, widespread adoption of HTP faces several challenges:

- High initial cost of sensors and platforms
- Large data volume and computational requirements
- Standardization and calibration issues
- Environmental variability under field conditions
- Limited accessibility for small breeding programs

Addressing these challenges requires development of low-cost sensors, standardized protocols, and user-friendly data analysis pipelines.

6. Future Prospects and Thrust Areas

The future of high throughput phenotyping lies in deeper integration with genomics, artificial intelligence and crop modelling. Development of cost-effective, multi-trait phenotyping platforms adaptable across crops and environments is essential. Real-time phenotyping combined with decision support systems will enable breeders and farmers to make timely and informed

decisions. Furthermore, phenotyping under diverse and climate-resilient environments will play a crucial role in breeding crops adapted to future climatic scenarios.

7. Conclusion

High Throughput Phenotyping has emerged as a critical technology for modern agriculture, addressing the limitations of conventional phenotyping and enabling precise, large-scale trait measurement. By bridging the genotype–phenotype gap, HTP accelerates crop improvement, enhances genetic gain and supports sustainable agricultural practices. Continued technological innovation, interdisciplinary collaboration and capacity building are essential to fully realize the potential of high throughput phenotyping in global agriculture.

8. References

- Araus, J. L., Kefauver, S. C., Zaman-Allah, M., Olsen, M. S., & Cairns, J. E. (2018). Translating high-throughput phenotyping into genetic gain. *Trends in Plant Science*, 23 (5), 451-466.
- Hartmann, A., Czauderna, T., Hoffmann, R., Stein, N., & Schreiber, F. (2011). HTPheno: An image analysis pipeline for high-throughput plant phenotyping. *BMC Bioinformatics*, 12, 148.
- Jangra, S., Jangra, R., & Kumar, S. (2021). High-throughput phenotyping: A new frontier in crop improvement. *Journal of Pharmacognosy and Phytochemistry*, 10 (1), 1723-1730.
- Kumar, J., Pratap, A., & Kumar, S. (2015). Phenomics in crop plants: Trends, options and limitations. *Springer India*.
- Li, L., Zhang, Q., & Huang, D. (2014). A review of imaging techniques for plant phenotyping. *Sensors*, 14 (11), 20078-20111.
- Singh, D., Singh, C. K., Taunk, J., Tomar, R. S. S., Chaturvedi, A. K., & Gaikwad, K. (2022). Phenomics: Tools and applications in crop improvement. *Frontiers in Plant Science*, 13, 812841.
- Xiao, Y., Liu, H., Wu, L., Warburton, M., & Yan, J. (2022). Genome-wide association studies in plants: Advances and perspectives. *Molecular Plant*, 15 (2), 1-18.
- Yang, W., Feng, H., Zhang, X., Zhang, J., Doonan, J. H., Batchelor, W. D., Xiong, L., & Yan, J. (2020). Crop phenomics and high-throughput phenotyping: Past decades, current challenges and future perspectives. *Molecular Plant*, 13 (2), 187-214.
- Zhao, C., Zhang, Y., Du, J., Guo, X., Wen, W., Gu, S., Wang, J., & Fan, J. (2019). Crop phenomics: Current status and perspectives. *Frontiers in Plant Science*, 10, 714.

NATURAL TOXICANTS IN FORAGE CROPS

Article ID: AG-VO5-I12-137

***K. Nalini and C. Nithya**

Associate Professor (Agronomy), Department of Animal Nutrition,
Veterinary College and Research Institute, Namakkal, Tamil Nadu, India

*Corresponding Author Email ID: naliniagr@gmail.com

Introduction

Plants are protected against herbivores by many diverse physical and chemical means. Physical defenses include leaf hairs, spines, thorns, highly lignified tissues (eg. Wood) and growth habitat (eg. Prostrate form). Chemical defenses of plants include a bewildering array of often complex chemicals that are toxic or poisonous to various herbivores. These chemicals may be synthesized by the plant itself or may be produced by symbiotic or mutualistic fungi growing with the plants. The defensive chemicals produced by the plants are considered secondary compounds, as distinct from the primary compounds that are essential in plant metabolism. Secondary compounds (eg. Alkaloids) do not function directly in cellular metabolism but apparently are synthesized to serve as the plants defensive collection.

Chemicals synthesized by fungi are known as mycotoxins, which may be produced by fungi living on or in forage plants. Ergot disease in cumbu (**pearl millet**, *Pennisetum glaucum*), a common fodder crop in India, caused primarily by the fungus *Claviceps fusiformis*. The disease results in the formation of toxic fungal masses (*sclerotia*) in place of grains, which pose a significant health risk to livestock if consumed in contaminated feed or fodder. Ergot is the production of toxic alkaloids within the *sclerotia*, which remain active even after processing into feed. Consumption of contaminated fodder can cause a disease called ergotism, leading to a range of severe symptoms in animals:



Gangrene of extremities: Reduced blood flow can lead to tissue death in

the ears, tail, and hooves.,

Reproductive issues: This can include agalactia (failure of milk secretion) in lactating animals, reduced fertility, and abortions.

General health problems: Poor growth, reduced feed intake, lameness, hyperthermia (heat stress), and seizures may also occur.

Toxins of plant origin can be classified into several major categories, including alkaloids, glycosides, proteins and amino acids and phenolics (tannins). Alkaloids are bitter substances containing N in a heterocyclic ring structure. There are hundreds of different alkaloids, which are classified according to the chemical structure of the N containing rings.

For examples

- ***Trifolium alexandrinum*** (Berseem Clover) - is a key leguminous winter fodder crop in India. Phytochemical analyses have confirmed the presence of alkaloids, along with saponins and flavonoids. Saponins can cause bloat in ruminants if fed in high quantities.
- ***Crotalaria* species:** While some *Crotalaria* species are grown as fodder, they are known to contain toxic pyrrolizidine alkaloids. Poisoning incidents have been reported due to contamination of grain with *Crotalaria* seeds in India.
- ***Leucaena leucocephala*:** This tree fodder is high in protein and calcium. It is known to contain the toxic amino acid mimosine, which is structurally a non-heterocyclic compound but is a well-known anti-nutritional factor in this plant.
- ***Vigna unguiculata* (Cowpea):** This legume crop is rich in protein and also contains various phytochemicals, including alkaloids.

The presence and concentration of these alkaloids can vary significantly depending on the plant species, growing conditions, and maturity stage.

Phenolic compounds like condensed and hydrolysable tannins, are substances containing aromatic rings with one or more hydroxyl groups. The hydroxyl groups are chemically reactive and can react with functional groups of proteins to form indigestible complexes. The tannin-protein complexes are astringent and adversely affect feed intake. Oak poisoning is caused by tannins in oak browse. Many tree legumes used in tropical agroforestry can contain sufficient levels of tannins to impair animal performances.

Glycosides are composed of a carbohydrate portion linked to a noncarbohydrate group. Examples are cyanogenic glycosides, glucosinolates, saponins and coumarin glycosides. Their

toxicity is associated with the aglycone, such as cyanide in cyanogenic glycosides. Glycosides are hydrolysed by enzymatic action, releasing the aglycone, this often occurs when the plant tissue is damaged by wilting, freezing, mastication. The breakdown of cell structure releases the glycoside from storage vacuoles, allowing it to be hydrolyzed by enzymes in the cytosol and to release free cyanide. Many toxic amino acids occur in plants. One of the best known is mimosine a toxic amino acid in the tropical forage legume subabul. Other include lathrogenic amino acids in lathyrus, S-methyl-cysteine sulfoxide, metabolic product of forage brassicas.



Forage sorghum contains cyanogenic glycosides, from which free cyanide can be released by enzymatic action. The glycosides occur in epithelial cells of the plant, damage to the plant from wilting, trampling, frost, drought etc., results in the breakdown of the plant structure, causing exposure of the glycosides to the hydrolyzing enzymes and formation of free cyanide. Cyanide causes acute respiratory inhibition of enzyme cytochrome oxidase. Signs of poisoning include labored breathing, excitement, gasping, convulsion, paralysis and death. The cyanide potential and risk of poisoning decrease as forage sorghum mature. The acute cyanide poisoning may be greater when feeding sorghum hay than when grazing the fresh plant because of the more rapid dry matter intake. Ground and pelleted sorghum hay may be especially toxic because of the rapid rate of intake and cyanide release. Ensiling markedly reduces the cyanide risk. Nitrogen fertilization of forage sorghums enhances the cyanide risk. Special caution is needed when livestock is grazing lush, immature forage sorghum. Cattle death on sorghum pastures occur more frequently in late summer or early fall, following an overnight frost.

Oxalate poisoning: Many tropical grasses contain high levels of oxalate. Upon ingestion by ruminants, oxalate complexes dietary Ca and forms insoluble calcium oxalate. This leads to

disturbances in Ca and P metabolism involving excessive mobilization of bone minerals. Prolonged grazing by cattle and sheep of some tropical grass species can result in hypocalcemia. Tropical grasses that have high oxalate levels includes Setaria sp., Brachiaria spp., buffel grass and kikuyu grass. Provision of mineral supplements high in Ca to grazing animals overcomes the adverse effect of oxalates in grasses.

These are the various natural toxicants present in the forages and they can be overcome by different management practices.



EXTENT AND PATTERNS OF WHEAT VARIABILITY IN PENINSULAR INDIA

Article ID: AG-VO5-I12-138***Rajendra Lokhande and Sanjay Chitodkar**

*Senior Research Assistant, Agricultural Research Station, MPKV Niphad Dist: Nashik
Maharashtra 422 203, India

Assistant Professor, Agricultural Research Station, MPKV Niphad Dist: Nashik Maharashtra

*Corresponding Author Email ID: lokhanderajesh928@gmail.com

Abstract

Wheat (*Triticum aestivum* L.) is a major staple food crop across the globe, supplying a significant share of daily caloric requirements to millions of people. In India, it ranks second after rice in both area under cultivation and overall consumption. Traditionally, wheat cultivation has been largely confined to the northern Indo-Gangetic plains; however, increasing attention is now being given to its cultivation in Peninsular India. This region, encompassing states such as Maharashtra, Karnataka, and Andhra Pradesh, is characterized by distinct agro-climatic conditions that pose certain constraints while also offering new possibilities for wheat production. The present article examines the genetic variability, agro-climatic suitability, and ongoing breeding initiatives in Peninsular India that focus on improving wheat productivity in this comparatively less-studied region.

Introduction

Wheat plays a vital role in India's food security and agricultural economy, and the country is among the leading producers of wheat globally. Although wheat production is largely concentrated in the northern parts of India, Peninsular India has traditionally contributed less to the overall wheat area and output. This limited adoption is mainly due to the region's unique agro-climatic constraints, including relatively higher temperatures, semi-arid conditions, restricted availability of irrigation, and a shorter crop duration compared to the Indo-Gangetic plains. When inappropriate varieties are grown under such conditions, these factors often result in lower productivity and reduced economic returns for farmers.

However, in recent years, progress in wheat breeding, coupled with improved agronomic and crop management practices, has created new opportunities for expanding wheat cultivation in Peninsular India. The region encompasses a broad spectrum of agro-climatic zones, ranging from humid coastal belts to dry inland areas, leading to considerable variability in growing environments. Harnessing the existing genetic diversity in wheat is therefore crucial for developing varieties that are well adapted to these heterogeneous conditions. This article reviews the present scenario of wheat cultivation in Peninsular India, highlights the importance of genetic variability, and discusses ongoing breeding efforts focused on developing high-yielding, stress-tolerant, and climate-resilient wheat varieties suitable for the region.

Genetic Variability available in wheat crop

Genetic variability encompasses the range of inherited traits present among wheat genotypes that determine their ability to adapt to different environments, tolerate abiotic and biotic stresses, and achieve stable productivity. In Peninsular India, where climatic conditions are often sub-optimal for wheat cultivation, the role of genetic variability becomes particularly crucial. Wheat improvement programmes in the region have therefore concentrated on identifying and developing genotypes capable of withstanding high temperatures, limited moisture availability, and shorter crop durations that are characteristic of peninsular agro-ecosystems.

Several wheat varieties have been specifically developed or successfully adapted for cultivation in Peninsular India, including NIAW 1415, DWR 162, MACS 2496, and HW 2004. These varieties possess traits such as heat and drought tolerance along with a relatively shorter maturity period, making them well suited to the brief winter season of the region. For instance, NIAW 1415 is recognized for its stable performance under elevated temperature conditions, which are frequently encountered in Maharashtra and parts of Karnataka. Similarly, MACS 2496 has demonstrated better adaptation in moisture-stressed environments, owing to its improved water-use efficiency and lower irrigation requirement.

The significance of genetic variability in wheat improvement cannot be overemphasized. A broad genetic base equips plant breeders with essential resources to develop varieties that can endure the harsh and variable climatic conditions of Peninsular India while sustaining desirable yield and grain quality. Moreover, enhanced genetic diversity contributes to greater resilience

against pests and diseases, which tend to be more severe in warmer regions, thereby ensuring greater yield stability and long-term sustainability of wheat cultivation in the peninsula.

Agro-Climatic Adaptation of Wheat in Peninsular India

The agro-climatic environment of Peninsular India differs markedly from that of the northern wheat-producing regions. While several constraints limit wheat cultivation in this zone, the region also offers considerable scope for productivity gains through the use of appropriately adapted varieties. Multiple environmental and management-related factors influence wheat growth and performance in Peninsular India, as outlined below.

High temperature:

Wheat crops in Peninsular India are frequently subjected to elevated temperatures, particularly during sensitive growth stages such as flowering and grain filling. Exposure to heat stress during these phases can adversely affect photosynthetic efficiency, hasten crop maturity, and ultimately reduce grain yield. Consequently, the development and adoption of heat-tolerant wheat varieties is essential for the region. Varieties such as NIAW 1415 and DWR 162 have exhibited better performance under high-temperature conditions, making them suitable for peninsular environments.

Drought conditions:

Erratic rainfall patterns and limited access to irrigation characterize large parts of Peninsular India, especially in states like Maharashtra and Karnataka. Under such circumstances, drought tolerance becomes a crucial attribute for wheat cultivation. Breeding programmes have emphasized the development of varieties with improved water-use efficiency, such as MACS 2496, which can maintain reasonable productivity under moisture-stressed conditions. These varieties reduce reliance on supplemental irrigation and are well suited to dryland and rainfed farming systems common in the region.

Soil diversity:

Peninsular India exhibits considerable variation in soil types, including alluvial, red, and black soils, each presenting distinct challenges and opportunities for wheat growth. Wheat improvement efforts have therefore targeted the development of genotypes capable of performing across a range of soil conditions. For example, black cotton soils possess high moisture-holding capacity but are prone to temporary water logging during periods of heavy

rainfall, necessitating varieties that can tolerate such conditions without significant yield penalties.

Shorter growing season:

Compared to northern India, the wheat-growing period in Peninsular India is relatively short due to milder winter temperatures. As a result, early-maturing wheat varieties that complete their life cycle within a limited time frame are preferred. Such varieties enable farmers to efficiently integrate wheat into existing cropping systems, particularly where double cropping or crop rotations involving pulses, maize, or sorghum are widely practiced.

Pest and disease pressure:

The warmer climatic conditions prevailing in Peninsular India favor the incidence and spread of several wheat diseases, including rusts and leaf blights. To minimize yield losses, breeding for resistance to major pests and diseases has been a key priority. The development and dissemination of disease-resistant varieties are essential for achieving stable and sustainable wheat production, especially in the context of changing climate and increasing biotic stress pressures.

Wheat Improvement Strategies and Future Directions

The development of wheat varieties suited to the conditions of Peninsular India has been a sustained effort undertaken by national and international agricultural research organizations, including the Indian Council of Agricultural Research (ICAR), various state agricultural universities, and global institutions such as the International Maize and Wheat Improvement Center (CIMMYT). Breeding programmes within these institutions emphasize the integration of multiple desirable traits—namely heat and drought tolerance, early maturity, and resistance to major diseases—to develop high-yielding wheat varieties capable of performing well under the region's challenging agro-climatic conditions.

In recent years, the adoption of advanced breeding approaches, including marker-assisted selection (MAS) and genomic selection, has significantly enhanced the efficiency of wheat improvement programmes. These modern tools allow breeders to precisely identify and track genes associated with important adaptive traits, thereby speeding up the development of improved varieties. For instance, genes conferring drought tolerance from indigenous wheat germplasm or wild wheat relatives can be successfully introgressed into elite, high-yielding backgrounds to strengthen resilience under moisture-limited environments.

Alongside conventional varietal development, increasing attention is being directed toward the potential of hybrid wheat, which holds promise for achieving substantial yield advantages over traditional open-pollinated varieties. Although hybrid wheat research is still at a relatively nascent stage, its successful development could play a transformative role in enhancing wheat productivity in Peninsular India.

Overall, the prospects for wheat cultivation in Peninsular India are encouraging. Continued investment in research and breeding is expected to result in the release of more climate-resilient, high-yielding wheat varieties tailored to the region. Coupled with supportive agricultural policies, improved crop management practices, and enhanced access to irrigation and quality inputs, wheat production in Peninsular India has the potential to emerge as a significant contributor to the country's total wheat output.

Conclusion

Wheat cultivation in Peninsular India, though historically limited, is gaining increasing importance in the context of rising food demand, climate variability, and the need to diversify wheat-growing regions in the country. The unique agro-climatic conditions of the peninsula—characterized by higher temperatures, moisture stress, diverse soil types, and shorter growing seasons—pose significant challenges to wheat production. However, these constraints also highlight the critical role of genetic variability and targeted breeding in developing varieties capable of adapting to such environments.

Research efforts by national and international institutions have led to the identification and development of wheat varieties with improved heat and drought tolerance, early maturity, and resistance to major pests and diseases, making wheat cultivation more feasible and sustainable in Peninsular India. The use of advanced breeding tools, such as marker-assisted and genomic selection, has further strengthened the efficiency of varietal improvement programs. In addition, emerging approaches like hybrid wheat offer promising avenues for enhancing productivity in the region.

Overall, the integration of well-adapted wheat varieties with improved agronomic practices, supported by continued research investment and enabling policy frameworks, can significantly enhance wheat productivity in Peninsular India. With sustained efforts, the region has the potential to contribute meaningfully to India's wheat production, thereby strengthening

national food security and improving the livelihoods of farmers in diverse peninsular agro-ecosystems.

References

- Kakanur Jagadeesha, Y., Navathe, S., Krishnappa, G., Ambati, D., Baviskar, V., Biradar, S., Magar, N., Mishra, C., Mamrutha, H., Govindan, V., Singh, G. and Singh, G. (2024), Multi-Environment Analysis of Nutritional and Grain Quality Traits in Relation to Grain Yield Under Drought and Terminal Heat Stress in Bread Wheat and Durum Wheat. *J Agro Crop Sci*, 210: e12763. <https://doi.org/10.1111/jac.12763>
- Nilesh Magar, Suresh Dodake, Sunil Umate and Rajendra Lokhande. 2023. Recommended wheat varieties for Peninsular Zone of India. *AgroScience Today*, Volume 4 (12) p 723-726.
- Nilesh Magar, Umesh Kabale, Kiran Gaikwad and Bharat Malunekar. 2024. Wheat Crop: Evolution and Present Research Status in India. *AgroScience Today*, Volume 5 (7) p 0909-0913.
- SK Dagade, SS Dodake and NM Magar. Genetic variability, character association and path coefficient analysis in bread wheat (*Triticum aestivum* Desf.). *J Pharmacogn Phytochem* 2020; 9 (6):2149-2155.
- Nilesh Madhavrao Magar, Bharat Malunekar and Suresh Dodake. 2025. Phule Shashwat - Resilient, Reliable, and Ready for Late Sowing. *AgroScience Today*, Volume 06 (06) p 1128-1133.
- Nilesh Magar, Bharat Malunekar, Umesh Kamble and Kiran Gaikwad. 2025. Phule Anurag-A New Blast Resistant Bread Wheat Variety for Farmers of Maharashtra and Karnataka. *AgroScience Today*, Volume 06 (01) p 1066-1068.
- Magar N, Dodake S, Gadekar D, Game B, Lokhande R, Mhaske B, Patil Y. Phule Satwik (NIAW 3170): A soft bread wheat variety for North Western Plains and Peninsular Zone of India. *Curr Agri Res* 2024; 12(1): 348-355.
- Magar N, S Dodake, D Gadekar, B Game, Y Patil, B Mhaske, B Malunekar, S Chitodkar and R Lokhande. 2024. NIAW 4028 (Phule Anurag): A new blast resistant bread wheat variety for restricted irrigation conditions of Peninsular India. *Journal of Cereal Research* 16 (2): 213-224

- S Dodake, N Magar, U Kachole and R Lokhande. 2022. NIDW-1149 - A New durum Wheat Variety for Peninsular Zone under Restricted Irrigation Condition. *AgroScience Today*, Volume 03 (06) p 405-407.
- M Nilesh, S Dodake, D Gadekar, B Mhaske, B Game, Y Patil, R Lokhande, B Malunekar and S Chitodkar. 2025. NIAW 4114 (Phule Shashwat): A New High Yielding Bread Wheat Variety for Late Sown Irrigated Conditions of Peninsular Zone in India. *Journal of Cereal Research* 17 (2): 213-220. <http://doi.org/10.25174/2582-2675/2025/168007>
- B. C. Game, P. P. Khandagale, N. M. Magar, B. M. Ilhe. 2025. Evaluation of fungicides for the management of Leaf Blight Disease in Wheat (*Triticum aestivum* L.). *J. Mycopathol. Res.* 63(2): 399-404



Volume: 05 Issue No: 12

AGRI-TECH STARTUPS AND THE ECONOMICS OF FARMER INCOME GROWTH IN INDIA

Article ID: AG-VO5-I12-139***Sharwani Sai Katkuri**

PG Research Scholar, Department of Agricultural Economics, MPKV, Rahuri Dist.

Ahilyanagar (MS) India-413 722.

*Corresponding Author Email ID: sharwani.k18@gmail.com

Abstract

India's agri-tech startup ecosystem has expanded rapidly over the past decade and is increasingly viewed as a critical lever for enhancing farm incomes. Drawing on evidence from NITI Aayog, the World Bank, FAO, NABARD and allied institutional sources, this article evaluates the economics of agri-tech startups to doubling farmers' incomes. Between 2012–13 and 2018–19, average monthly farm income rose from ₹6,426 to ₹10,218, while the number of agri-tech startups increased from fewer than 50 in 2014 to over 6,200 by 2023, supported by strong venture capital inflows and public funding. The analysis shows that agri-tech influences income through productivity gains, improved market access, post-harvest value addition and diversification. However, income doubling remains conditional on credit expansion, digital infrastructure, policy stability and farmer segmentation. Agri-tech thus acts as a growth accelerator rather than a standalone solution.

Key words : Farmer income; Digital agriculture; Technological change; Institutional constraint

Introduction

Raising farm incomes remains a central objective of India's agricultural development strategy, given the dominance of small and marginal farmers and persistent inefficiencies in production and marketing systems. National survey data indicate a 62 per cent increase in average farm household income between 2012–13 and 2018–19, yet income levels remain modest and uneven across regions. Parallel to this, India has witnessed a rapid expansion of agri-tech startups, supported by venture capital, government incubation programmes and digital agriculture

initiatives. These developments have renewed policy interest in technology-led income enhancement. This article examines the nature, scale and limitations of agri-tech-led income growth, using recent institutional evidence to assess whether technological innovation can realistically deliver the goal of doubling farmers' income.

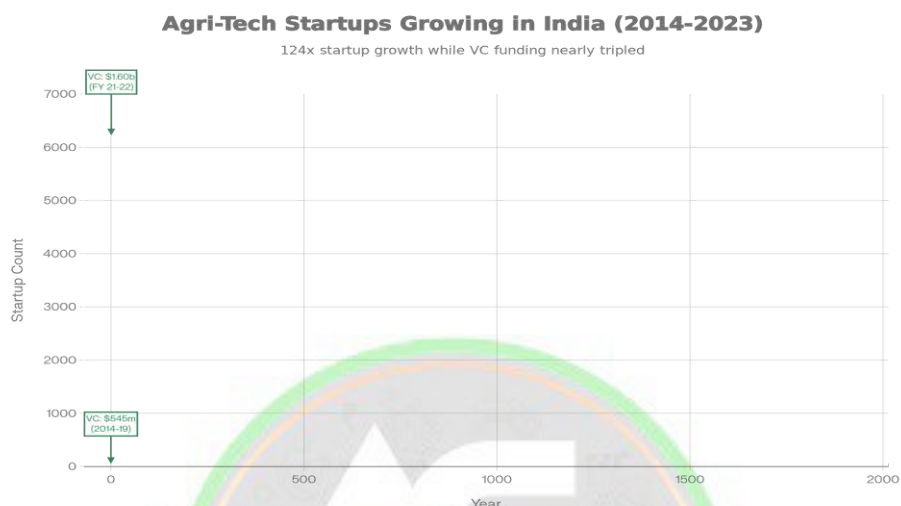


Figure 1. Explosive Growth of Agri-Tech Startups in India (2014-2023)

Image source: *Author's compilation based on NITI Aayog (2023), Startup India (2023), and NABARD (2023)*

CONTENTS

Current Status of the Agri-Tech Ecosystem

India's agri-tech ecosystem has expanded rapidly in scale but remains constrained by limited digital penetration and institutional depth. Digital adoption in Indian agriculture is estimated at around 12 per cent, significantly lower than in advanced and emerging economies such as the United States (95 per cent), Brazil (75 per cent) and China (57 per cent). Farmer Producer Organisations (FPOs) have emerged as key institutional vehicles, with over 7,100 entities collectively representing nearly 22 lakh farmers, the majority of whom are small and marginal. Despite this scale, market integration remains partial, with only 454 FPOs onboarded onto the ONDC digital commerce platform. A more binding constraint is financial inclusion, as only about 21 per cent of FPOs maintain formal banking linkages, limiting their capacity to invest in technology and scale operations.

Income Enhancement Mechanisms of Agri-Tech

Agri-tech startups influence farmer incomes through multiple economic channels. Productivity gains arise from precision technologies such as AI-based advisories, IoT-enabled sensors and drone applications, which optimize input use, reduce wastage and improve timing of farm operations, resulting in income gains of 15–25 per cent. Market access and price realisation improve through direct-to-buyer digital platforms that reduce intermediary margins, particularly in a supply chain where nearly 85 per cent of transactions remain informal. Post-harvest value addition through cold storage, logistics and processing technologies mitigates physical losses estimated at 8–20 per cent across commodities, translating into potential income increases of 30–50 per cent. Additionally, diversification towards horticulture and allied activities enables risk reduction and higher value capture, with evidence indicating substantially higher average incomes for diversified farm households.

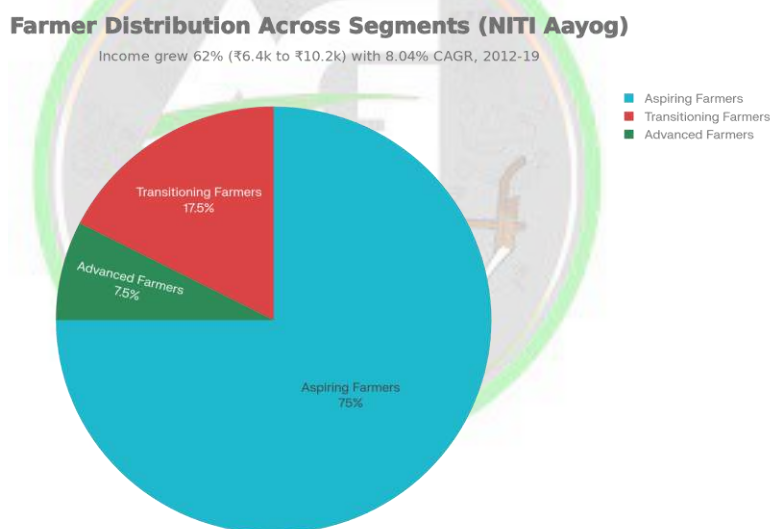


Figure 2. Farmer Distribution Across Income Segments in India

Source: Author's compilation based on NITI Aayog (2017; 2023) and NSSO (2018–19)

Empirical Evidence of Income Growth

Institutional and survey-based evidence confirms that technology adoption, when combined with supportive policies, can generate significant income growth. Documentation by ICAR indicates that over 75,000 farmers have more than doubled their incomes through convergence of schemes, market access and technological interventions. National household survey data report a 62 per cent increase in average farm income between 2012–13 and 2018–19,

corresponding to an annual growth rate exceeding 8 per cent. Parallel trends in rural consumption expenditure, which increased by nearly 188 per cent between 2011–12 and 2023–24, suggest improvements in purchasing power and welfare. Private sector assessments further estimate that agri-tech adoption could contribute 25–35 per cent income growth and add approximately USD 95 billion to the broader economy.

Segment	Share	Characteristics	Income Doubling Timeline	Primary Requirements
Aspiring Farmers	70-80%	Small, rain-fed	10-15 years	Land reforms, irrigation, subsidized tech
Transitioning Farmers	15-20%	Medium, entrepreneurial	10-12 years	Credit linkage, FPO participation, infrastructure
Advanced Farmers	1-2%	Large, commercial	5-7 years	Precision agriculture, value chains, market access

Table 1. Farmer Segmentation, Income Doubling Timelines, and Key Requirements

Source: Author's compilation based on NITI Aayog (2017; 2023), NSSO (2018–19), and ICAR (2022)

Farmer Segmentation and Systemic Constraints

The income impact of agri-tech is highly differentiated across farmer categories, as recognized in the NITI Aayog roadmap. Small and rain-fed farmers, who constitute 70–80 per cent of the farming population, face longer timelines for income doubling and require complementary investments in irrigation, land reforms and subsidized technology. Medium and entrepreneurial farmers benefit more rapidly from credit access, FPO participation and infrastructure, while large commercial farmers can achieve faster gains through precision agriculture and integrated value chains. However, systemic barriers persist across segments, including incomplete digital infrastructure under AgriStack, low digital literacy, policy volatility in trade and pricing regimes, infrastructure deficits in storage and logistics, and limited access to institutional credit, with nearly four-fifths of FPOs remaining outside formal banking systems.

Conclusion

Agri-tech startups have emerged as a significant catalyst for income growth in Indian agriculture by improving efficiency, market integration and value realisation. Empirical evidence suggests that income gains of 25–35 per cent over a decade are achievable for many farmers when technology adoption is supported by credit, infrastructure and institutional convergence. However, doubling of farmer income cannot be achieved through technological interventions alone. Structural constraints related to land, water, credit access, digital capacity and policy stability continue to shape outcomes. Agri-tech should therefore be viewed as a complementary accelerator within a broader development framework rather than a standalone solution to rural income challenges.

References

- 1) NITI Aayog (2023). *Digital Agriculture in India: Pathways to Transformation*.
- 2) NITI Aayog (2025). *Reimagining Agriculture: A Roadmap for Frontier Technology*.
- 3) World Bank (2022). *Enabling the Business of Agriculture*.
- 4) FAO (2022). *Digital Agriculture and Rural Transformation*.
- 5) NABARD (2023). *Annual Report: Agri-Startups and FPO Digitisation*.
- 6) ICAR (2022). *Doubling of Farmers' Income: Status and Strategies*.
- 7) NSSO / MoSPI (2023–24). *Household Income and Consumption Surveys*.
- 8) McKinsey & Company (2023). *How Agtech Can Transform Indian Agriculture*.
- 9) PIB, Government of India (2023–24). *Digital Agriculture and FPO Initiatives*.
- 10) FAO (2023). *E-Agriculture and Smallholder Transformation*.
- 11) <https://www.niti.gov.in/verticals/agriculture-technology>
- 12) <https://www.sanskritiias.com/current-affairs/transforming-the-agricultural-sector-niti-aayog-report>

Volume: 05 Issue No: 12

FOOD LOST BEFORE IT REACHES THE PLATE: THE COLD STORAGE PROBLEM

Article ID: AG-VO5-I12-140***Sharwani Sai Katkuri**

PG Research Scholar, Department of Agricultural Economics, MPKV, Rahuri Dist.

Ahilyanagar (MS) India-413 722.

*Corresponding Author Email ID: sharwani.k18@gmail.com

Abstract

India's agricultural paradox lies in producing large volumes of food while losing a substantial share before consumption. Nearly 30% of horticultural output is wasted annually due to inadequate cold chain infrastructure, translating into economic losses exceeding ₹92,000 crore. Despite being a leading producer of fruits and vegetables, India's cold storage capacity of about 31.8 million tonnes falls far short of the estimated requirement of over 61 million tonnes. This deficit is compounded by severe shortages in pack houses, refrigerated transport, and ripening facilities, causing rapid deterioration of perishables. The problem is structural rather than production-driven, reflecting logistical, institutional, and investment gaps. Strengthening integrated cold chain systems can significantly reduce food losses, enhance farmer incomes, stabilize prices, and lower the environmental footprint of wasted food. The study underscores that cold chain expansion is central to achieving food security, sustainability, and efficient agricultural value chains in India.

Key words : Cold chain infrastructure; Post-harvest losses; Food waste; Agricultural logistics

Introduction

India occupies a prominent position in global agriculture, particularly in fruit and vegetable production. However, this production advantage is undermined by extensive post-harvest losses resulting from weak storage and transportation systems. Perishable commodities often deteriorate before reaching markets due to the absence of temperature-controlled logistics. As a result, food waste coexists with nutritional insecurity, revealing deep inefficiencies within

agricultural value chains. Cold storage and allied infrastructure are therefore not supplementary facilities but essential components of modern agri-food systems. Understanding the scale, causes, and economic consequences of cold chain inadequacy is critical for designing effective policy and investment strategies.

Contents

Scale and Economic Significance of Food Losses

Post-harvest losses in India vary across commodities, with fruits and vegetables exhibiting the highest vulnerability due to their biological perishability. Losses in this segment average around 12%, substantially higher than cereals and pulses. In value terms, total annual losses exceed ₹92,000 crore, representing foregone income, wasted resources, and missed food security opportunities. Evidence from organized sectors such as dairy demonstrates that temperature-controlled systems drastically reduce losses, highlighting the role of logistics rather than production constraints.

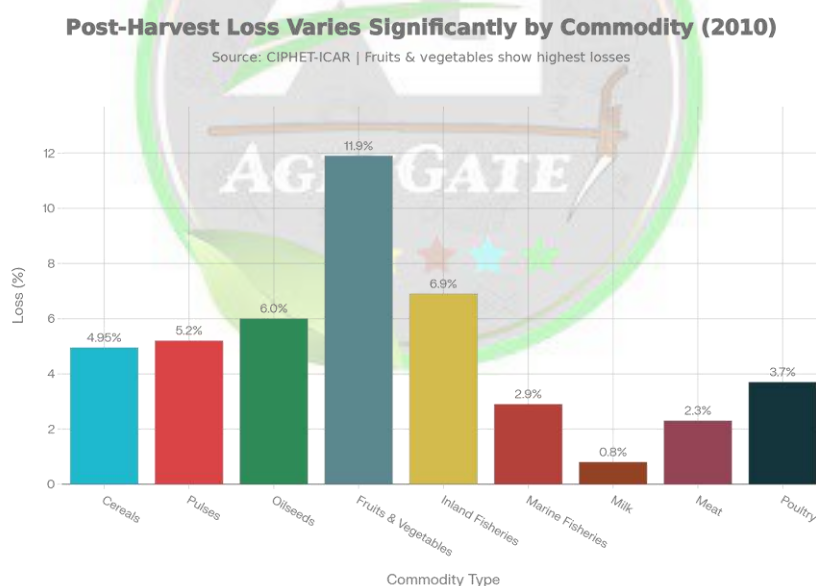


Figure 1. Post-harvest loss varies significantly by commodity (2010).

Source: CIPHET-ICAR (2010).

Cold Chain Capacity and Structural Gaps

India's cold storage infrastructure comprises fewer than 7,000 facilities with capacity sufficient for only about half of national requirements. Capacity is heavily concentrated in a few states and skewed toward potato storage, leaving high-value perishables inadequately protected.

Complementary infrastructure shows even sharper deficits, with pack houses, refrigerated vehicles, and ripening chambers operating at less than 15% of required levels.

Infrastructure Component	Current Availability	Requirement	Gap	% Shortfall
Pack Houses	250 units	70,000 units	69,750 units	99.6%
Reefer Vehicles	9,000-10,000	62,000	52,000-53,000	85%
Ripening Chambers	812 units	9,131 units	8,319 units	91%
Cold Storage Capacity	31.82 million MT	61.13 million MT	29.31 million MT	47%

Source:NCCD (2015); Sathguru Management Consultants (2017), *Cold Chain Report*.

Value Chain Inefficiencies and Farmer Impact

The absence of integrated cold chains disrupts the farm-to-market continuum. Farmers frequently face distress sales or outright wastage during peak harvests when prices collapse and storage options are unavailable. Transportation delays without refrigeration accelerate quality degradation, while high rental costs make cold storage inaccessible for small producers. Consequently, a significant share of output never reaches consumers.

Environmental and Global Dimensions

Food loss carries a substantial environmental cost. Wasted food embodies wasted water, energy, and land, while decomposing produce contributes to greenhouse gas emissions. Globally, food waste accounts for a carbon footprint comparable to that of major industrialized nations. Cold chain expansion therefore offers both economic and environmental returns by reducing waste-related emissions.

Investment Needs and Policy Interventions

Bridging the cold chain gap requires investments approaching ₹90,000 crore, primarily in pack houses and refrigerated transport. Government schemes such as PM Kisan SAMPADA Yojana

and MIDH provide capital subsidies, yet implementation remains uneven. Financing barriers, power supply constraints, and regulatory complexity limit private participation, particularly among farmer collectives.

Pathways for Integrated Solutions

Effective cold chain development demands a systems approach integrating storage, transport, processing, and digital monitoring. Cluster-based infrastructure, public–private partnerships, and technology adoption such as solar-powered units and IoT monitoring can enhance efficiency. Institutional coordination and skill development are equally critical to ensure optimal utilization.

Conclusion

India's cold storage shortage represents a structural bottleneck that converts agricultural abundance into economic loss and food insecurity. The persistence of high post-harvest losses reflects logistical failures rather than production deficits. Strategic investment in integrated cold chain infrastructure offers high economic returns, environmental benefits, and improved farmer welfare. As climate variability intensifies and demand for perishables grows, strengthening cold chains becomes an indispensable pillar of sustainable agricultural development. Without decisive action, food waste will continue to undermine both rural livelihoods and national nutrition goals.

References

- 1) FAO. (2019). *The state of food and agriculture 2019: Moving forward on food loss and waste reduction*. FAO.
- 2) FAO. (2015). *Food wastage footprint and climate change*. FAO.
- 3) CIPHET. (2010). *Assessment of quantitative harvest and post-harvest losses of major crops*. ICAR.
- 4) Ministry of Food Processing Industries. (2014). *Report of the task force on cold-chain infrastructure*. Government of India.
- 5) Ministry of Food Processing Industries. (2022). *PM Kisan SAMPADA Yojana: Progress report*. Government of India.
- 6) NITI Aayog. (2021). *Post-harvest management and food loss assessment in India*. Government of India.
- 7) National Horticulture Board. (2014). *Cold storage capacity statistics*. Government of India.

- 8) Sathguru Management Consultants. (2017). *Cold chain infrastructure in India*.
- 9) World Bank. (2020). *Reducing food loss and waste for sustainable development*.
- 10) Maersk. (2024). *Cold chain logistics in India: Challenges and opportunities*.
- 11) Hyperatmos. (2024). *India food waste in cold chains*.
- 12) NABARD Consultancy Services. (2023). *Cold chain utilization and financing constraints*.
- 13) Global Food Cold Chain Council. (2015). *Cold chain and climate impact assessment*.
- 14) Ministry of Agriculture & Farmers Welfare. (2024). *Agricultural statistics at a glance*.
- 15) Invest India. (2023). *Cold chain infrastructure and investment potential in India*.



ORGANIC SPICE FARMING: A GROWING TREND IN SUSTAINABLE AGRICULTURE

Article ID: AG-V05-I12-141

Vasanth S¹ and Arul Prakash A²

¹ Ph. D scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, HC&RI, TNAU, Coimbatore.

² Research scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, HC&RI, TNAU, Coimbatore.

*Corresponding Author Email ID: vasanth1506@gmail.com

Introduction

Spices have been the heart of global cuisine, trade, and culture for thousands of years. From the fragrant cardamom of the Western Ghats to the fiery chilies of Andhra Pradesh, spices are more than just flavor enhancers - they are cultural icons, economic drivers, and healing agents. In recent decades, a new movement has emerged within this ancient world: **organic spice farming**. Combining age-old agricultural wisdom with modern ecological principles, organic spice farming is reshaping how spices are grown, marketed, and valued.



What Is Organic Spice Farming?

At its core, **organic spice farming** is the cultivation of spices without synthetic chemicals- no chemical fertilizers, pesticides, herbicides, or genetically modified organisms (GMOs). Instead, farmers rely on natural soil fertility, biodiversity, and biological pest control.

The result is a product that's more environmentally friendly, healthier for consumers, and often more profitable for growers.

But organic farming is more than a method - it's a philosophy rooted in sustainability and respect for nature. It emphasizes soil health, ecosystem balance, and social responsibility.

Why the Growing Interest?

Global interest in organic products is skyrocketing. Research shows that consumers increasingly prefer foods that are perceived as healthier, more natural, and free from chemical residues. Spices are no exception. Organic spices now command premium prices in international markets, creating lucrative opportunities for farmers in developing countries.

Several key factors are driving the trend:

- **Health awareness:** People are more concerned about pesticide residues and the long-term effects of chemicals in food.
- **Environmental concerns:** Farmers and consumers alike recognize the importance of protecting soil, water, and biodiversity.
- **Economic potential:** Organic certification can open access to high-value export markets.
- **Government support:** Many countries, including India, offer subsidies and technical support for organic farming.

The Benefits of Organic Spice Farming

Organic spice farming offers a wide range of benefits—environmental, economic, and social.

1. Healthier Soil and Ecosystems

Chemical fertilizers and pesticides might boost short-term yields, but they degrade soil health over time. Organic spice farming rebuilds soil fertility using:

- **Compost and organic manure**
- **Cover crops and green manures**
- **Crop rotation and intercropping**

These methods increase soil organic matter, improve water retention, and enhance nutrient cycling. A healthy soil ecosystem supports resilient crops and reduces dependency on external inputs.

2. Reduced Environmental Pollution

Conventional farming often washes chemicals into water bodies, harming aquatic life and contaminating drinking water sources.

Organic methods minimize chemical runoff, which protects rivers, lakes, and groundwater. In spice-producing regions with rich biodiversity-like the Western Ghats of India-this protection is crucial. By avoiding harmful chemicals, organic spice farming helps preserve delicate ecosystems and wildlife habitats.

3. Higher Market Value and Premium Prices

Organic spices typically fetch higher prices than conventionally grown spices. In international markets, organic certification is recognized as a seal of quality and sustainability. For farmers, this can translate into better income, stronger bargaining power, and access to niche markets.

Products like **organic turmeric, black pepper, cinnamon, and cardamom** have high demand in the US, Europe, and Japan - markets that **pay premium** prices for certified organic goods.

4. Enhanced Food Safety and Consumer Trust

Consumers choose organic spices because they perceive them as safer and cleaner. With growing awareness of food safety issues, organic certification builds trust. For food processors and exporters, this trust becomes a brand advantage.

5. Climate-Friendly Agriculture

Organic farming practices contribute to climate change mitigation. Techniques such as:

- **Mulching**
- **Reduced tillage**
- **Agroforestry**

help sequester carbon in soil and vegetation. This makes organic spice farming part of a broader climate-smart agriculture movement.

Challenges and How Farmers Overcome Them

Despite the benefits, organic spice farming is not without challenges. Transitioning from conventional to organic systems requires time, knowledge, and investment. Some of the main hurdles include:

1. Transition Period and Certification Costs

To become certified organic, land must be free from prohibited chemicals for a certain number of years - typically 2–3 years. During this period, farmers may face:

- Lower yields
- High certification costs

- Lack of immediate premium pricing

Solutions: Government subsidies, cooperative certification programs, and organic farming training help farmers through the transition phase.

2. Pest and Disease Management

Without synthetic pesticides, farmers need alternative pest control methods - like botanical extracts, pheromone traps, and biological agents. Initially, managing pests organically can be challenging.

Solutions: Training programs, farmer field schools, and partnerships with agricultural research institutions provide farmers with effective integrated pest management (IPM) strategies.

3. Knowledge and Technical Support

Organic farming demands a greater understanding of ecological processes. Farmers require knowledge on:

- Soil biology
- Nutrient management
- Natural pest-control strategies

Solutions: Extension services, organic farming workshops, and farmer-to-farmer learning networks are essential.

4. Market Access and Infrastructure

Even with organic certification, farmers need reliable access to markets and supply chains.

Solutions: Forming cooperatives, participating in farmer producer organizations (FPOs), and using digital marketplaces help connect producers with buyers.

Popular Organic Spices and Their Uses

Organic spice farming is flourishing across the globe, but especially in countries with traditional spice cultures like India, Sri Lanka, Indonesia, and Morocco. Let's explore some popular organic spices and why they matter.

1. Turmeric

Renowned for its vibrant color and medicinal properties, turmeric is a staple in Indian kitchens. Organic turmeric is in high demand among consumers seeking natural anti-inflammatory benefits.

It's used in:

- Cooking
- Herbal teas
- Natural cosmetics

2. Black Pepper

Often called the “king of spices,” black pepper is widely used around the world. Organic black pepper is prized for its bold flavor and absence of chemical residues. It’s a key ingredient in global cuisines and an important export commodity.

3. Cardamom

Known as the “queen of spices,” cardamom is expensive and labour-intensive to grow. Organic cardamom fetches high prices, especially in European and Middle Eastern markets.

4. Cinnamon

Organic cinnamon is favoured for its aromatic sweetness and uses in baking, beverages, and natural remedies.

5. Chili Peppers

Chilies are used fresh, dried, or powdered. Organic varieties are popular among consumers focused on health and flavor purity.

Organic Spice Farming and Sustainable Livelihoods

Organic spice farming doesn’t just protect the environment-it sustains communities.

Empowering Small-Scale Farmers

In many regions, spice cultivation is dominated by smallholder farmers. Organic farming gives them:

- Better prices
- Value-added product opportunities
- Collective bargaining power through producer groups

Women and Youth in Organic Agriculture

Organic farming often creates opportunities for women and young people. Tasks like seedling management, value addition (e.g., making spice blends), and marketing can generate additional income at the household level.

Fair Trade and Social Equity

When organic farming is combined with fair trade principles, it ensures:

- Fair wages

- Safe working conditions
- Community development projects

This strengthens rural economies and promotes social equity.

Innovations Boosting Organic Spice Farming

Modern technology is helping spice farmers improve productivity and sustainability.

1. Digital Platforms and Traceability

Consumers increasingly want to know where their spices come from. Digital traceability tools let farmers and companies provide full supply-chain transparency- tracking a spice from seed to shelf.

2. Climate-Smart Farming Practices

Data-driven tools, weather forecasts, and soil sensors help farmers make better decisions, protect crops, and reduce risk.

3. Organic Inputs and Biofertilizers

The market for organic seeds, biofertilizers, and natural pest repellent products is growing. These products support healthier crops without compromising organic standards.

How Governments and Organizations Are Supporting the Movement

Recognizing its economic and environmental value, governments and international organizations are investing in organic agriculture:

- **Subsidies for certification and inputs**
- **Training and extension services**
- **Export facilitation schemes**
- **Research on organic crop management**

For countries like India-which produces a significant share of the world's spices-this support helps farmers compete in global markets while protecting natural resources.

Consumer Trends Driving Demand

Consumers are no longer satisfied with just flavor-they want food that aligns with their values. Organic spices appeal to buyers for several reasons:

- **No chemical residues**
- **Perceived health benefits**
- **Environmental stewardship**
- **Ethical sourcing**

Online retail platforms, health food stores, and natural product brands have all contributed to rising demand.

Success Stories and Case Studies

Across tropical and subtropical regions, farmers are finding success through organic spice farming:

- In **Kerala's spice belts**, farmers transitioning to organic pepper and cardamom have seen better soil health and premium markets.
- In **Gujarat and Rajasthan**, organic chili producers export to health-food markets in Europe.
- In **Sri Lanka**, organic cinnamon is marketed as a premium culinary and wellness product.

These stories highlight how organic farming can boost both livelihoods and landscapes.

How You Can Support Organic Spice Farming

Consumers can play a part in growing this movement:

- Choose certified organic spices
- Support brands with transparent sourcing
- Learn about spice origins
- Try growing your own organic herbs and spices

Even small choices-like buying organic turmeric or pepper-help promote sustainable agriculture standards globally.

Conclusion

Organic spice farming represents a harmonious blend of tradition and innovation. It returns farming to ecological principles that nourish the soil, respect biodiversity, and support rural communities. For consumers, it offers authentic flavor, peace of mind, and products aligned with health and sustainability values. In a world grappling with climate change, biodiversity loss, and chemical pollution, organic spice farming is more than a trend-it's a meaningful shift toward agriculture that feeds people and restores the planet.

Volume: 05 Issue No: 12

ECONOMICS OF MILLETS: FROM POOR MAN'S FOOD TO SUPERFOOD

Article ID: AG-VO5-I12-142**¹*Sharwani Sai Katkuri and ²Snehal Choudhary**

¹Post Graduate Research Scholar, Department of Agricultural Economics, MPKV, Rahuri Dist.-
Ahilyanagar (MS) India-413 722.

²Post Graduate Research Scholar, Department of Horticulture, MPKV, Rahuri Dist.-
Ahilyanagar (MS) India-413 722.

*Corresponding Author Email ID: sharwani.k18@gmail.com

Abstract

Millets have re-emerged as a strategic crop at the intersection of nutrition security, climate resilience, and sustainable agricultural economics in India. Historically contributing nearly 40% of India's grain basket prior to the Green Revolution, millet cultivation declined sharply due to policy and procurement biases favoring rice and wheat. Recent global recognition through the United Nations' declaration of 2023 as the International Year of Millets, coupled with India accounting for nearly 41% of global millet production, has renewed policy and market interest. This paper evaluates the economic revival of millets through an integrated assessment of nutritional advantages, production and market dynamics, and policy interventions. Evidence indicates that despite declining cultivated area, improving yields, emerging price premiums, and state-led procurement initiatives present a strong case for targeted intervention. However, sustained transformation requires coordinated action across pricing policy, institutional procurement, value-chain development, and consumer demand generation.

Key words : Millets; Nutrition Economics; Climate-Resilient Agriculture; Agricultural Policy; Sustainable Food Systems

Introduction

Millets represent a unique convergence of agronomic resilience, nutritional density, and economic sustainability within India's agricultural system. Officially designated as "Nutri-

Cereals” by the Government of India in 2018, millets include a diverse group of small-seeded cereals such as bajra, jowar, ragi, and minor millets that thrive under low-input, rain-fed conditions. Despite their historical prominence, millet cultivation experienced prolonged marginalization following the Green Revolution, as policy incentives and procurement mechanisms concentrated on rice and wheat. The renewed global and national focus since 2023 marks a turning point, positioning millets as a solution to intertwined challenges of malnutrition, climate stress, and income vulnerability among smallholders. This article examines whether current economic, market, and policy trends can support a sustained millet resurgence.

CONTENTS

Production Trends and Structural Decline

India’s millet sector reflects a **paradoxical** trajectory. Between 2010–11 and 2020–21, cultivated area declined by over 28%, resulting in a production contraction of nearly 1% CAGR, despite yield improvements exceeding 2% annually. This indicates that productivity gains were insufficient to offset declining farmer participation. Production remains geographically concentrated, with Rajasthan, Karnataka, Maharashtra, and Uttar Pradesh accounting for a majority of output, driven by agro-climatic suitability rather than market incentives. Pearl millet dominates production due to superior yields, while nutritionally superior crops such as finger millet occupy a relatively minor share.

Nutrition Economics and Welfare Implications

The economic justification for millet promotion is anchored in their exceptional nutritional density. Millets outperform rice and wheat in calcium, iron, zinc, dietary fiber, and glycemic response—attributes directly linked to India’s persistent malnutrition burden. Finger millet alone provides over 50 times the calcium content of rice, while pearl millet delivers substantially higher iron levels critical for addressing anemia. Empirical health studies associate millet consumption with reduced postprandial glucose levels, improved lipid profiles, and enhanced micronutrient absorption, translating into long-term healthcare cost savings and productivity gains.

Market Signals, Pricing and Export Momentum

Market dynamics have begun to shift in favor of millets. In 2024, farm-gate prices exceeded Minimum Support Prices by 15–20% in major producing states, reflecting rising private demand from food processing and wellness segments. MSP revisions since 2017 have

cumulatively doubled prices for select millets, strengthening producer incentives. Export performance has also improved, with millet exports growing steadily and reaching over USD 34 million, supported by expanding international health-conscious consumer markets. These trends indicate early-stage commercialization beyond subsistence and welfare-driven narratives.

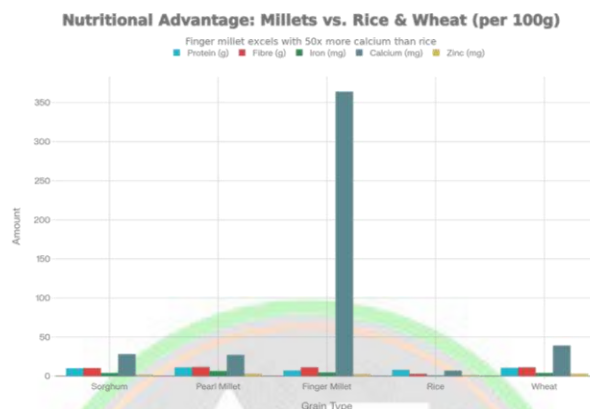


Figure 1. Nutritional Advantage of Millets over Rice and Wheat (per 100 g)

Source: Author's compilation based on ICMR–NIN (2017) Indian Food Composition Tables and FAO (2023)

Policy Interventions and State-Level Innovations

State-led initiatives have demonstrated measurable impact. Odisha's integrated millet mission achieved productivity doubling and income increases exceeding 100% through coordinated production, procurement, and consumption strategies..

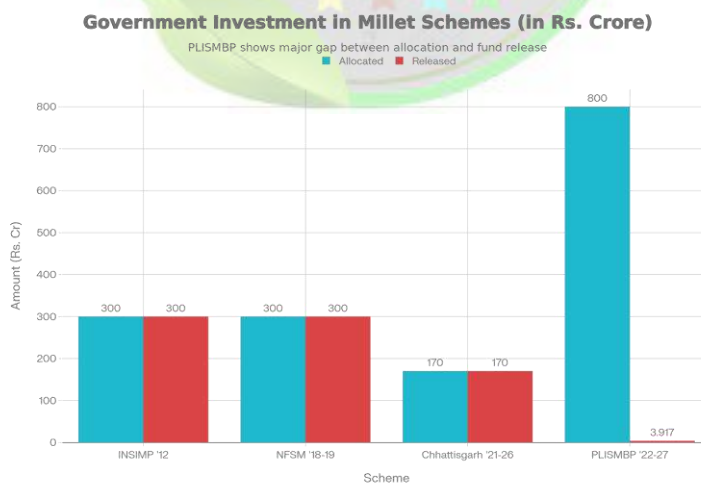


Figure 2. Government Investment in Millet Promotion Schemes in India (₹ crore)

Source: Author's compilation based on Ministry of Agriculture & Farmers Welfare (NFSM, PLISMBP guidelines), Union Budget documents, and State Budget documents of Chhattisgarh

Andhra Pradesh and Chhattisgarh have adopted similar institutional models combining input support, aggregation through FPOs, and public procurement. At the national level, schemes such as NFSM–Nutri Cereals and the Production Linked Incentive Scheme for millet-based products aim to strengthen both supply and value addition. However, implementation gaps, particularly low fund utilization and limited procurement scale, constrain aggregate impact.

Conclusion

Millets have transitioned from marginal subsistence crops to strategic instruments for nutrition security, climate adaptation, and inclusive agricultural growth. Empirical evidence highlights their superior nutritional profile, improving price realization, and rising institutional support. Yet, market forces alone remain insufficient to internalize millets' positive environmental and health externalities. The period following the International Year of Millets represents a critical policy window. Sustained revival requires assured procurement at scale, rationalized pricing incentives, investment in processing infrastructure, and systematic integration into public nutrition programs. With coordinated action, millets can reclaim their historical role—not as inferior alternatives, but as central pillars of a resilient and sustainable food system.

References

- 1) FAO (2023). *International Year of Millets: Final Report*.
- 2) Government of India (2018). *Declaration of Millets as Nutri-Cereals*. Ministry of Agriculture & Farmers Welfare.
- 3) NITI Aayog (2023). *Promoting Millets in Diets: Best Practices Across States/UTs*.
- 4) Directorate of Economics & Statistics (2021). *Area, Production and Yield of Food Grains*.
- 5) Government of India (2024). *Agricultural Statistics at a Glance*.
- 6) IBEF (2025). *Millets: The Nutritional Powerhouse*.
- 7) FAO (2023). *Climate Resilience of Millets*.
- 8) IIM Ahmedabad (2024). *Millets for Sustainable Development in India*.
- 9) NITI Aayog (2023). *Nutritional Composition of Millets*.
- 10) MicroSave (2024). *Millets and Nutrition Security in India*.
- 11) Financial Express (2024). *Millet Prices Rule Above MSP on Rising Demand*

Volume: 05 Issue No: 12

SEEDS: THE SECRET TO BUMPER CROPS! HOW NSCL DELIVERS TOP-QUALITY PADDY AND MORE

Article ID: AG-VO5-I12-143**Kesoju Ravali¹, Irayya Hiremath² and Mohammad Shafiqurrahman³**

¹M.Sc. (Agriculture) in Genetics and Plant Breeding, Junior Executive (Agri.), National Seeds Corporation Ltd. (NSCL), Warangal, Telangana, India

²M.Sc. (Agriculture), Assistant Manager, National Seeds Corporation Ltd.(NSCL), Warangal, Telangana, India

³Seed Certification Officer, Telangana State Seed and Organic Certification Authority (TGSOCA), Warangal, Telangana, India

*Corresponding Author Email ID: kesojuravali123@gmail.com

Introduction

Quality paddy seeds have high genetic purity, uniform size/shape/color, high germination (80%-90%), good vigor, and are free from weeds, diseases, and other crop seeds, ensuring strong, uniform plants, fewer off-types, and higher yields with traits like good tillering, disease resistance, and proper maturity for the specific variety. Key characteristics include high physical purity (no debris/damaged grains), high viability (germination), vigor (strength), and specific varietal traits like grain type (long, bold, slender) and maturity period

SEEDS...!! SEEDS...!! SEEDS...!!! They're the powerhouse behind every thriving farm, carrying the genetic magic of top varieties. Imagine sowing seeds that are pure, vigorous, and ready to burst into high yields— that's the dream for every farmer. Good-quality seeds at the right time and price mean bigger harvests and fatter profits. Thanks to the Seeds Act of 1966, India has strict standards for production, testing, and certification. But with demand skyrocketing, where do you turn? Enter NSCL—the government's seed champion since the Green Revolution.

Meet NSCL: Your Go-To for Reliable Seeds

National Seeds Corporation Ltd

The National Seeds Corporation Ltd. (NSCL), a Miniratna Category-I company under the Ministry of Agriculture, kicked off in 1963 to produce foundation and certified seeds. Today, it boasts 5 farms, 11,603 registered growers across India, and a massive network: 11 regional offices, 48 area offices, 30 seed production centers, 107 marketing points, 76 processing plants, 7 AC storage facilities, 2 veggie packing units, and even a DNA fingerprinting lab. They produce 567 varieties of 78 crops—from cereals and pulses to oilseeds, fibers, fodder, and veggies. Their mission? Deliver reliable seeds for cereals, pulses, fibers, oilseeds, veggies, and fruits. Vision? Become India's top producer of foundation, and certified seeds for food grains and beyond.

A Bounty of Crops at Your Fingertips

NSCL covers it all:

- Cereals: Paddy stars like MTU-1010 (Cotondora Sannalu), Swarna (MTU-7029), Samba Mahsuri (BPT-5204).
- Pulses: Black gram (T-9, Tulasi), green gram (Shika), bengal gram (JG-11).
- Oilseeds: Groundnut (Dharani, Kadri-6), sesamum (Swetha).
- Fibers & Fodder: Sunhemp (Ankur), sorghum (CSV-33MF).
- Veggies: Bhendi (Pusa Bhindi-5), brinjal (Pusa Kranti), tomato (Arka Samrat), and more like chillies, gourds, and methi.

Spotlight on Secunderabad Regional Office & Warangal Powerhouse

NSCL's Secunderabad office serves Telangana and Andhra Pradesh with 5 area offices (Lallaguda, Warangal, Nandyal, Kurnool, Guntur). Warangal steals the show, covering 15 districts like Khammam, Karimnagar, and Warangal. It dominates paddy seed production (60-80% of NSCL's paddy output), certified by TSSOCA. Why? Warangal's climate is paddy paradise, and farmers swear by its superior quality—seeds that deliver consistent results.

Warangal offers 60+ paddy varieties

Top Paddy Picks for Telangana Farmers

- MTU-7029 (Swarna): Medium slender, 150-day Kharif star. High adaptability, blast-tolerant, nitrogen-responsive—perfect for stable yields and tasty rice.
- MTU-1001 (Vijetha): Medium slender, 135-day Kharif/125-day Rabi. BPH/blast-tolerant, super dormant (4 weeks)—no weedy surprises.

- MTU-1010 (Cottondora Sannalu): Long slender, 120-day Rabi mega-variety. BPH/blast-tolerant, highly adaptable.
- MTU-1064 (Amara): Medium slender, 150-day Kharif. Flood/BPH-tolerant, non-lodging, low shattering.
- MTU-1075 (Pushyami): Long slender, 135-day Kharif. Non-lodging, BPH-tolerant.
- MTU-1156 (Tarangini): Long bold, 120-day Rabi. Semi-dwarf, blast/BPH-tolerant, photo-insensitive.
- BPT-3291 (Sona Mahsuri): Medium slender, 135-140 days. Gall midge/neck blast-resistant.
- BPT-5204 (Samba Mahsuri): Medium slender, 140-145 days. Excellent cooking quality, non-dormant.
- IR-64: Long slender, 115-120-day Kharif mega-variety. Semi-dwarf, high-yielding, disease-resistant.



How NSCL Ensures Seed Perfection

From farm to field, NSCL nails quality. At Warangal's 6 godowns (3 with processing plants), post-harvest magic happens under certification officers: precleaning, grading, gravity separation, stone removal, then secure packing. It's step-by-step science for pure, vigorous seeds.

Why Choose NSCL?

Confused at sowing time? NSCL, as a central government powerhouse, offers premium seeds at small-farmer prices. Ditch the guesswork—grab their paddy varieties for Telangana and watch your yields soar.

NATIONAL SEED CERTIFICATION: PHASES AND PROCEDURE

Article ID: AG-VO5-I12-144**Kesoju Ravali¹, Irayya Hiremath² and Mohammad Shafiqurrahman³**

¹M.Sc. (Agriculture) in Genetics and Plant Breeding, Junior Executive (Agri.), National Seeds Corporation Ltd. (NSCL), Warangal, Telangana, India

²M.Sc. (Agriculture), Assistant Manager, National Seeds Corporation Ltd.(NSCL), Warangal, Telangana, India

³Seed Certification Officer, Telangana State Seed and Organic Certification Authority (TGSOCA), Warangal, Telangana, India

*Corresponding Author Email ID: kesojuravali123@gmail.com

Introduction

In the world of agriculture, the seed is the most fundamental input. To ensure that farmers receive seeds of the highest quality—true to their variety and free from disease—the government implements a rigorous system known as Seed Certification. This is a voluntary process that acts as a quality assurance guarantee, maintaining genetic purity and identity across different seed generations.

Core Functions of Seed Certification

The primary objective of the certification agency is to maintain and make available high-quality seeds to the public.

Key functions include:

Certifying Seeds: Handling all notified kinds and varieties.

Verification of Seed Source: Ensuring the seed used for planting is authentic and legally purchased.

Field Inspections: Monitoring crops to ensure they meet minimum field standards and are free from seed-borne diseases.

Seed Testing: Analyzing samples in laboratories for germination percentage, moisture content, and the presence of inert matter.

Granting Certification: Issuing official tags, labels, and seals that certify the seed's quality.

Classes of Seed and Identification

Seed production follows a strict hierarchy. Each class is identified by a specific colored tag to help farmers identify the quality:

Seed Class Description (Tag Color):

Breeder Seed Directly controlled by the originating plant breeder; used for the initial increase of Foundation seed. (Golden Yellow)

Foundation Seed The progeny of Breeder seed; supervised to maintain specific genetic identity and purity. (White)

Certified Seed The progeny of Foundation seed; produced in large quantities for commercial sale to farmers. (Azure blue)

The Six Phases of Seed Certification

The journey from a planted field to a certified bag of seed involves six broad phases:



Receipt and Scrutiny of Application: The initial review of the producer's request.

Verification of Seed Source: Checking the class and source of the seed used for raising the crop.

Field Inspections: Verifying that the standing crop conforms to prescribed field standards.

Post-Harvest Supervision: Monitoring processing and packing to prevent contamination.

Seed Sampling and Analysis: Laboratory testing for genetic purity and health.

Grant of Certificate: The final issuance of certification tags and sealing of containers.

Registration Procedure: Step-by-Step

1. Application (Form-I)

Seed Certification is voluntary. Producers must submit an application in Form-I (in triplicate).

Timeline: Must be submitted within 21 days of sowing (with a 7-day grace period).

Area Limit: A single application can cover a maximum of 25 acres. Areas larger than this are treated as separate units.

2. Compulsory Documents for Registration

To register, a producer must provide:

Demand Draft (DD) for certification charges.

Original Breeder/Foundation seed tags and purchase bills.

Pattadar passbook copies and Aadhaar cards.

“Form II” and land lease documents (if applicable).

3. Field Inspection and Online FIRs

Once registered, a Seed Certification Officer (SCO) is allotted to the area. The SCO conducts inspections to check for “off-types” or diseases. If the crop fails, a rejection order is issued immediately. If successful, an online Field Inspection Report (FIR) is generated.

4. Processing and Sampling

After harvest, seeds are moved to a Seed Processing Unit (SPU).

Sampling: The SCO takes representative samples to test for Germination, Moisture content, and Physical purity.

Bulking: Producers can apply to “bulk” lots of the same variety and stage for easier processing.

5. Final Tagging and Certification

If the lab results meet the prescribed standards, the ADSC (Assistant Director of Seed Certification) allots the final tags:

White Tags for Foundation seeds.

Blue Tags for Certified seeds.

Form II: The final certificate number is allotted to the seed lot one day after the tags are issued.

Conclusion

Seed certification is a meticulous “field-to-bag” process. By following these steps, the certification agency ensures that the “Quality Seeds to Farmers” mission is achieved, protecting both the farmer’s investment and the nation’s food security.

Volume: 05 Issue No: 12

SHAPING THE FUTURE OF SMART AGRICULTURE: POLICY FRAMEWORKS AND THE RISE OF AGRI-TECH STARTUPS

Article ID: AG-VO5-I12-145

**Dr Balaji Parasuraman^{1*}, S S Sharmitha², S Savitha Shree³, S Jayasuriya⁴ and
Mugilan K⁵**

*** ¹Professor, ^{2,3,4} PG Student in MBA ABM, ⁵PhD Scholar**

Department of Agricultural and Rural Management, TNAU, Coimbatore-641003.

Tamil Nadu, India

***Corresponding Author Email ID: pbalaji@tnau.ac.in**

Introduction

The government has implemented several initiatives, including the Prime Minister's Employment Generation Programme (PMEGP), Start-up India, Skill India, and the Pradhan Mantri Kaushal Vikas Yojana, to generate employment, enhance skill development, and stimulate economic growth. This study assessed the effectiveness and performance of diverse start-up ecosystems by examining sectoral and state-wise contributions. Start-ups in India have significantly influenced the national employment landscape (CJ *et al.*, 2022). Notably, following the COVID-19 pandemic from 2020 to 2022, 173,244 jobs—representing 27.54 percent of start-up job creation in India—were generated through Start-up India initiatives in Southern India, primarily facilitated by the Department for Promotion of Industry and Internal Trade (DPIIT). These initiatives are therefore instrumental in advancing economic development.

Table 1. State-wise Number of Direct Employment Generated through Startups Recognized by Promotion of Industry and Internal Trade DPIIT under Startup India (2020 to 2022)

States/UT	2020	2021	2022
Andhra Pradesh	3007	2359	3061
Karnataka	27457	20994	24487
Kerala	5639	7616	9967

Lakshadweep	7	0	0
Puducherry	68	205	237
Tamil Nadu	7794	9956	17191
Telangana	8982	10030	14187
Southern India	52954	51160	69130
India	161587	198629	268823

Source: India Stat 2022

Start-up Ecosystem

Chandiok (2016) investigated the impact of Start-up India on start-up growth, highlighting factors such as improved access to affordable capital, streamlined patent filing, research and development credits, and simplified entry processes that contribute to the initiative's effectiveness in promoting economic growth. Mason and Brown (2014) underscored the importance of connecting large companies, entrepreneurs, academics, researchers, human resources professionals, government agencies, and funding organizations to establish a robust and sustainable ecosystem. Korreck (2019) analyzed the Indian start-up ecosystem, identifying growth drivers, founder motivations, challenges faced by start-ups, and foundational pillars supporting their development. Munshi (2019) provided an overview of the Indian start-up ecosystem, incorporating global best practices and focusing on the dynamics of food start-ups. Gerard *et al.* (2020), through case studies, demonstrated that the food and agriculture sector has attracted educated youth motivated by ideas, passion, and innovation.

These entrepreneurs and start-ups address gaps in the agri-value chain by delivering efficient products, technologies, and services to both farmers and consumers, while also creating opportunities for innovative platforms in agri-business and agri-entrepreneurship. Iyappan *et al.* (2020) identified critical elements and resources necessary to strengthen the agripreneurial ecosystem in Tamil Nadu, ensuring resource availability for agripreneurship development. Li *et al.* (2020) examined the role of incubators in nurturing successful business ventures, the influence of government policy in promoting entrepreneurship, the establishment of university business incubators, and the provision of grants to academic institutions for incubator development. Chaudhari (2020) identified ten emerging trends driving growth in the Indian start-up ecosystem and highlighted areas where these trends can be leveraged. Srishailam *et al.* (2022) argued that agri start-ups represent significant human capital in the Indian agricultural economy

and are essential partners for innovation-led agricultural growth, emphasizing the need for strong alliances with promising agri start-ups to achieve sustainable progress. Mitra *et al.* (2023) identified key elements of the start-up ecosystem, including knowledge hubs, public policy, entrepreneurship, and city economies, as drivers of entrepreneurship in smart cities. Raj *et al.* (2024) presented a comprehensive analysis of various aspects of the agri-start-up ecosystem in India.

Notable Startups in Smart Agriculture

Startup	Focus Area	Description	Country
Green Collar Agritech	AI for pest & disease management	AI-driven platform for early detection and control of pests	India
Farmonaut	Satellite crop monitoring	Provides real-time satellite imagery and data analytics for farms	India
AgroStar	Direct input marketplace	Mobile app connecting farmers to quality Agri-inputs	India
CropX	Soil sensor & analytics	Smart soil sensors with cloud-based analytics for irrigation	USA
Taranis	Aerial imagery & AI crop monitoring	Uses drones and AI to analyse crop health and predict threats	Israel
Blue River Tech	Robotic weed control	Robots that identify and spray herbicides only on weeds	USA
AgroSpace	Weather forecasting	Hyperlocal weather prediction platform for farmers	India
Small Robot Company	Autonomous farming robots	Robots for planting, monitoring, and harvesting crops autonomously	UK
Eruvaka Technologies	IoT-based aquaculture management	IoT solutions for fish farm water quality and feeding	India
Aker Technologies	Automated greenhouse and soil sensors	Solutions to optimize greenhouse conditions and soil health	India

Performance of Startups

Subash *et al.* (2016) examined technology transfer in agricultural research and development and concluded that sufficient funding is crucial for fostering agri-based startups, expanding agribusiness, and promoting agri-entrepreneurship. Building on these findings, Singh (2016) analyzed the financial challenges encountered by Indian startups and noted that the government has implemented several initiatives to cultivate an entrepreneurial environment and incentivize emerging startups through innovative programs. In addition to funding, governmental support has facilitated business establishment through advancements in information technology. Rao and Kumar (2016) reviewed the role of angel investors in the Indian startup ecosystem and emphasized that achieving India's projected growth requires the development of a robust support system for startups. The persistent issue of limited financial resources may be addressed by increasing the participation of angel investors and networks, highlighting their significance alongside government initiatives.

Vijayan *et al.* (2020) identified critical factors influencing the creation and performance of agri-startups, as reported by entrepreneurs. Ghosh (2020) determined that operational longevity is a significant determinant and that angel investors and equity financing serve as primary funding sources for startups. While government policy has not yet produced substantial effects, recent state-level business reforms have begun to yield positive results. Scillitoe *et al.* (2022) demonstrated that college groundwork and a culture of creativity and innovation facilitate market entry for Indian startups, whereas an emphasis on personal achievement can hinder this process. Fujita *et al.* (2022) introduced a quantitative method to assess startup ecosystem characteristics, which supports the promotion of unicorns and the development of global investment networks involving unicorns and venture capitalists. Syamala *et al.* (2023) reported that agri-tech startups are unevenly distributed across India and analyzed the market segments they serve at various stages. Saqib (2023) examined Zomato's differentiation strategy in the Indian food market using the business model canvas, thereby contributing to the theoretical understanding of business model innovation as a source of competitive advantage. Goswami *et al.* (2023) identified insufficient capital and ineffective sales and marketing strategies as common causes of startup failure in India, leading to competitive disadvantages and financial losses. Lehmann (2023) guided corporate and accelerator managers, as well as startups, in selecting the most appropriate corporate accelerators.

Digital and Sustainable Start-up Value Chain Development

Sharma *et al.* (2018) demonstrated that the introduction of start-up digital technology in the agricultural sector has increased productivity and efficiency through mechanization and automation. Singh *et al.* (2020) reported that the Indian start-up ecosystem exhibits more positive than negative sentiments, concluding that its future aligns with the vision of Digital India. To address issues of inclusion, start-ups are encouraged to internalize open innovations within national food policy. This paradigm shift necessitates rigorous research into innovative business models and the establishment of robust collaboration and licensing agreements among companies, universities, and governmental agencies (Nuthalapati *et al.*, 2021). Singh *et al.* (2020) conducted an exploratory study on the evolving digitalization of the food system, providing a general description of the functions and interoperability mechanisms of start-ups, without a detailed analysis of technology products or marketing tactics. Nam *et al.* (2024) addressed a knowledge gap in the AI business ecosystem literature, highlighting current opportunities and challenges and emphasizing the importance of ongoing dialogue among government agencies, leading technology companies, and AI start-ups to foster a more sustainable AI business ecosystem.

Existing Innovations and Technologies Identified for Start-ups

E-commerce: Start-ups are transforming traditional retail by developing innovative e-commerce platforms, enabling personalized shopping experiences, and optimizing supply chains.

Artificial Intelligence: Start-ups are leveraging AI for diverse applications, including natural language processing, computer vision, autonomous vehicles, and predictive analytics.

Food Technology: Start-ups are developing personalized nutrition plans and utilizing blockchain to enhance supply chain transparency. They are also creating vertical farming systems for urban agriculture and employing fermentation technology to produce alternative dairy products.

Financial Technology (FinTech): Start-ups in this sector are transforming financial management, investment, and transaction processes. They utilize blockchain for secure and transparent transactions, develop mobile payment solutions to enable rapid and secure financial transfers, and create robo-advisors that provide automated, algorithm-driven financial planning services.

Agricultural Technology (AgTech): AgTech start-ups are advancing agriculture through precision farming, which employs Internet of Things (IoT) sensors and drones to monitor crop

health and soil conditions, thereby optimizing water and fertilizer use. Vertical farming start-ups cultivate crops in controlled, stacked environments, often in urban areas, reducing land use and increasing yield.

Transportation and Logistics: Start-ups in this sector are advancing autonomous vehicle technology to achieve safer and more efficient transportation of people and goods. They are also exploring hyperloop technology, which offers the potential for ultra-high-speed travel through low-pressure tubes and could transform intercity travel. Drone delivery services represent another innovation, providing rapid and efficient delivery solutions for e-commerce and other sectors, thereby reducing delivery times and costs.

Clean Energy and Sustainability: Start-ups in this sector focus on developing sustainable energy solutions. They are innovating in solar power technology by creating more efficient photovoltaic cells and advanced solar storage systems. Electric vehicle start-ups are improving battery technology and expanding charging infrastructure to support the adoption of electric vehicles.

Healthcare and Biotechnology: Healthcare start-ups are transforming the industry by developing telemedicine platforms that enable remote consultations and treatments, thereby increasing access to healthcare services. They are also pioneering wearable health devices that continuously monitor vital health metrics and deliver real-time data to users and healthcare providers.

Smart Farming: Smart farming, also referred to as smart agriculture, involves adopting advanced technologies and data-driven operations to optimize and enhance sustainability in agricultural production. Technologies used in smart farming include artificial intelligence (AI), automation, and the Internet of Things (IoT). The primary objective is to establish data-driven farm operations that increase productivity while addressing challenges such as food security, climate change, and resource scarcity.

Core Technologies of Smart Farming

The Internet of Things (IoT) comprises networks of connected devices and sensors that gather data on crops, soil, livestock, and agricultural machinery. Data analytics and cloud computing enable the processing of extensive datasets to produce actionable insights for irrigation, fertilizer application, and pest management. Artificial intelligence (AI) and machine learning (ML) facilitate predictive analytics for weather forecasting, disease detection, and yield estimation. Automation and robotics, including the use of robots and drones, enhance the

precision of seeding, fertilizing, harvesting, and spraying, while also minimizing environmental impact.

Information and communications technology (ICT) supports efficient data management, transfer, and real-time decision-making in agriculture. Technologies implemented in smart farming include precision plant nutrition and irrigation systems, greenhouse climate control, and sensors for monitoring temperature, light, moisture, soil, and water. Software platforms facilitate data analysis, while positioning systems such as satellite and GPS, along with communication systems like LoRa WAN and mobile networks, provide essential infrastructure for these applications.

Ayaz *et al.* (2019) described IoT-based smart agriculture as a system in which interconnected sensors and devices optimize farm management through real-time data collection. Wolfert *et al.* (2017) reviewed the deployment of big data in agriculture, highlighting the integration of GPS, sensors, and analytics platforms to enable precision farming. Liakos *et al.* (2018) examined the use of AI and machine learning for irrigation, fertilization, and crop health monitoring. Kamilaris *et al.* (2017) identified communication technologies, including LoRa WAN and mobile networks, as primary enablers of IoT in agriculture. Collectively, these studies demonstrated that technology integration supports the development of sustainable, resilient, and efficient farming systems.

The Role of IoT in Agriculture

The IoT ecosystem in agriculture includes wireless sensor networks (WSNs), AI-powered analytics, cloud technology, and intelligent actuators, which together enhance real-time monitoring, predictive modelling, and automation (Mhlanga, 2023). These technologies enable several advancements. Smart irrigation systems optimize water use based on real-time soil moisture and climatic data, achieving water savings of up to 50% (Abbasi *et al.*, 2022). AI-driven pest and disease identification systems employ machine learning to detect early signs of infestations, reducing crop damage by 20 to 30% (Senoo *et al.*, 2024). Autonomous farm machinery, such as automated tractors, unmanned aerial vehicles (UAVs), and robotic harvesters, increases planting and harvesting efficiency while decreasing dependence on manual labor (Sadjadi & Fernández, 2023). Livestock tracking solutions use wearable IoT devices to monitor health indicators, dietary patterns, and physical activity, which reduces mortality rates and enhances productivity (Calicioglu *et al.*, 2019). IoT-enabled supply chain solutions,

including blockchain-integrated monitoring systems, improve food traceability and reduce post-harvest losses by 40% (Senoo *et al.*, 2024). The integration of these technologies indicates that IoT-driven smart farming is essential for addressing food security challenges and strengthening agricultural resilience (Mhlanga, 2023).

Applications of IoT and Automation

IoT-based tractors: Leading manufacturers, including John Deere and New Holland, provide autonomous tractors equipped with GPS, geographic information systems (GIS), and cloud computing. These integrated technologies reduce operational overlap, improve turning efficiency, and ensure centimetre-level precision.

Harvesting robots: Automated harvesters, such as SW 6010, Octinion, SWEEPER, and FFRobot, employ computer vision and machine learning to detect and pick fruit. These systems are especially beneficial in areas experiencing labor shortages that lead to substantial annual financial losses.

Drone (UAV) Applications

Soil and field analysis: Drones are used to survey erosion and evaluate soil fertility, providing data that inform crop selection decisions.

Planting: UAVs can disperse seed pods, facilitating the planting of as many as 100,000 trees per day.

Crop monitoring: UAV imaging assesses nutrient levels and monitors crop growth patterns.

Irrigation: UAVs identify water-stress zones and enable targeted irrigation.

Spraying: UAVs enable precise application of herbicides and pesticides, reducing chemical waste and minimizing environmental exposure.

Plant counting and gap detection: Aerial imagery integrated with artificial intelligence mapping evaluates stand density and generates yield forecasts.

Smartphone Integration- Mobile technologies offer accessible interfaces for rural farmers. Modern smartphones facilitate low-cost data collection through GPS, cameras, and sensors, supporting mobile services for field monitoring and agronomic guidance.

The Role of AI in Agriculture

The agricultural artificial intelligence (AI) ecosystem incorporates machine learning (ML), deep learning (DL), and big data analytics to optimize productivity, resource management, and sustainability. AI enhances decision-making by delivering predictive insights, automation,

and precision systems (Aijaz *et al.*, 2025). In crop prediction, machine learning models use satellite imagery, soil characteristics, and climate data to forecast yields with 90–92% accuracy, thereby increasing resource use efficiency (Aijaz *et al.*, 2025). For irrigation and fertilization, AI-integrated systems analyze soil moisture and weather data, resulting in a 25–30% reduction in water usage and a 20% decrease in fertilizer application (Nautiyal *et al.*, 2025). In pest and disease detection, AI-based image recognition algorithms identify early signs of crop diseases with up to 95% accuracy, reducing yield losses by 20–40% (Yun, 2024; Senoo *et al.*, 2024). Autonomous farm operations leverage AI-driven robotic systems, such as autonomous tractors, drones, and harvesters, to reduce labor requirements and improve operational precision (Kaur *et al.*, 2024). For livestock health monitoring, AI-powered vision and sensor technologies track animal activity, feeding behavior, and health patterns, thereby enhancing animal welfare and reducing mortality rates (FAO, 2025). In supply chain optimization, predictive models integrated with blockchain technology increase traceability and reduce post-harvest losses by 35–40% (Shahriar *et al.*, 2025).

The Role of ICT in Agriculture

Information and Communication Technology (ICT) significantly enhances productivity, sustainability, and knowledge dissemination within the agricultural sector. ICT facilitates connections among farmers, researchers, and policymakers, enabling timely data exchange and informed decision-making through digital tools and communication platforms.

Key Roles of ICT in Agriculture:

1. **Precision Farming:** ICT tools like GIS, GPS, and remote sensing optimize resource utilization, monitor soil and weather conditions, and enhance yield efficiency.
2. **Mobile-Based Services:** Smartphones and mobile applications deliver real-time weather information, market prices, and expert guidance to farmers, thereby supporting improved decision-making.
3. **Supply Chain & Traceability:** ICT ensures food traceability and transparency through blockchain technology, Radio Frequency Identification (RFID), and data management systems, thereby reducing post-harvest losses (FAO, 2025).
4. **Knowledge & Extension Services:** Digital platforms and e-agriculture initiatives address information gaps by providing training, education, and support to smallholder farmers (Mulungu, 2025).

5. Big Data & IoT Integration: ICT integrates with Artificial Intelligence (AI) and the Internet of Things (IoT) to enable predictive analytics, early warning systems, and automated farm management.

Types of Sensors used in agriculture

Acoustic Sensors: Detect soil interactions and pest activity through sound analysis.

Optical Sensors: Measure light reflectance to estimate soil organic matter, minerals, and plant health.

Ultrasonic & Optoelectronic Sensors: Determine plant height, weed distribution, and canopy structure.

Electrochemical Sensors: Analyse soil nutrients, salinity, and pH.

Mechanical and Mass-Flow Sensors: Measure soil compaction and crop yield.

Eddy Covariance Sensors: Quantify gas fluxes (CO_2 , CH_4) between land and atmosphere, essential for carbon-footprint analysis.

LiDAR Sensors: Map land surfaces in 3D, estimate biomass, and monitor soil erosion.

Environmental and Economic Impact

Smart farming promotes efficient resource use, reducing water consumption and fertilizer application, thereby lowering greenhouse gas emissions (IBM, 2025). For example:

A Texas project uses soil moisture sensors and AI algorithms to optimize irrigation during droughts.

A California winery achieved a 26% yield increase and 16% water savings using data from satellite imagery and sensors.

A Kazakhstan smart greenhouse automatically regulates temperature and humidity to maintain optimal growth conditions.

In the UK, dairy farms use wearable sensors on cattle to monitor activity

Future of Smart Agriculture

The future of Smart Agriculture is shaped by rapid advancements in technologies and growing emphasis on sustainability, productivity, and climate resilience.

- i. **Artificial Intelligence (AI) Expansion:** AI will become central to agriculture, enabling predictive analytics for weather, pests, and yields, and providing actionable insights to farmers at scale.

- ii. **Robotics and Automation:** Advances in autonomous tractors, drones, and harvesting robots will reduce labor shortages and improve precision in operations.
- iii. **IoT and Sensor Networks:** The deployment of billions of IoT sensors globally will facilitate real-time monitoring of soil, crops, and livestock, optimizing input use and crop health.
- iv. **Precision and Climate-Resilient Farming:** Adoption of precision irrigation, smart nutrient management, drought-resistant seeds, and vertical farms will enhance resilience to climate change.
- v. **Blockchain for Traceability:** Secure supply chain tracking using blockchain will improve food safety and reduce fraud.
- vi. **Integrated Smart Farm Management Platforms:** Cloud-based digital platforms will unify data streams for resource tracking, digital advisory, and remote farm management.
- vii. **Sustainability and Carbon Footprint Monitoring:** Smart agriculture will increasingly focus on environmental sustainability, measuring and reducing carbon footprints, and promoting regenerative agriculture

Policy Framework for Smart Agriculture

Mainstreaming into Core Government Policy and Planning: To achieve maximum impact, Smart Agriculture, including Climate-Smart Agriculture, should be systematically integrated into national agricultural development policies, expenditure frameworks, and planning mechanisms. These policies must align with broader strategies for economic growth, poverty reduction, food security, and the achievement of sustainable development goals (SDGs) (FAO,2025).

Coordination and Integration Across Sectors: Effective policy frameworks emphasize inter-sectoral coordination among agriculture, climate change, water resource management, disaster risk reduction, and rural development at national, regional, and local governance levels (FAO,2025). This coordination reduces fragmentation and enables more efficient resource utilization.

Enabling Environment and Incentives: Governments must create an enabling environment by offering incentives such as payments for ecosystem services, subsidies for technology adoption, and improved access to credit (FAO,2025). Programs supporting Farmer-Producer Organizations (FPOs) and cooperative societies play a critical role in extending the benefits of smart agriculture to smallholders (Farmonout, 2025).

Technological Integration and Innovation Promotion: Policies encourage the adoption of digital agriculture technologies such as IoT, AI, drones, GIS, and satellite monitoring (Indiaai, 2025). Support for research & development, capacity building, and extension services is essential to maximize the adoption and impact of these technologies (Farmonout, 2025).

Climate-Smart and Sustainable Agriculture Synergy: Smart agriculture policies often intersect with climate-smart agriculture frameworks, addressing climate resilience, emission reductions, and sustainable natural resource management (Sustainable Finance Center, 2025). Support mechanisms such as the National Innovations on Climate Resilient Agriculture (NICRA) and the Pradhan Mantri Krishi Sinchayee Yojana in India exemplify policy initiatives that integrate productivity with sustainability.

Financial and Institutional Support

Government budgets are increasingly allocating funds for smart agriculture infrastructure, including cold chains, storage facilities, rural digital infrastructure, and market linkages. Financial mechanisms include direct support schemes, crop insurance, and investments in smart irrigation systems and digital marketplaces.

Policy Examples from India (2025)

The New National Agricultural Policy 2025 adopts a farmer-centric, digitally enabled approach that emphasizes crop diversification, cost reduction, climate adaptation, and export promotion. The policy prioritizes sustainability and technological modernization through strategies for price support, infrastructure development, and research (Farmonout, 2025). Programs introduced under this policy include AI-based crop monitoring and the promotion of digital advisory services, enabling farmers to make more precise decisions (Yuan *et al.*, 2025).

Asian Policy Trends for Smart Agriculture

Asian government policies prioritize technology adoption, market access, training, and international cooperation to accelerate the advancement of smart agriculture. However, gaps remain in risk prevention and standardization frameworks, indicating areas where policy improvement is required.

References

Abbasi, R., Martinez, P., & Ahmad, R. (2022). The digitization of agricultural industry – A systematic literature review on agriculture 4.0. *Smart Agricultural Technology*, 2, 100042.

- Aijaz, Nazish, He Lan, Tausif Raza, Muhammad Yaqub, Rashid Iqbal, and Muhammad Salman Pathan. "Artificial intelligence in agriculture: Advancing crop productivity and sustainability." *Journal of Agriculture and Food Research* (2025): 101762.
- Ayaz, Muhammad, Mohammad Ammad-Uddin, Zubair Sharif, Ali Mansour, and el-Hadi M. Aggoune. "Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk." *IEEE Access* 7 (2019): 129551-129583.
- Calicioglu, O., Flammini, A., Bracco, S., Bellù, L., & Sims, R. (2019). The future challenges of food and agriculture: An integrated analysis. *Sustainability*, 11(1), 222.
- Chandiok, S. (2016). India the world's fastest growing startup ecosystem: A study. *Amity Research Journal of Tourism, Aviation and Hospitality*, 1(2), 84–93.
- Chaudhari, S. L., & Sinha, M. (2021). A study on emerging trends in Indian startup ecosystem: big data, crowd funding, shared economy. *International Journal of Innovation Science*, 13(1), 1-16.
- CJ, S., B, V. & Krithika, J. (2022). IMPACT OF STARTUPS IN INDIAN GDP IN 2022. *EPRA International Journal of Multidisciplinary Research* 8(12), pp. 1-6.
- Fujita, M., Okudo, T., Nishino, N., & Nagane, H. (2022). Analyzing startup ecosystem through corporate networks based on investment relation of venture capitals in unicorns. *Procedia CIRP*, 112, 11-16.
- Gerard, M., Gupta, M., Srinivas, K., & Sastry, R. K. (2021). An insight of intellectual property management practices in the Agriculture Research System. *The Indian Journal of Agricultural Sciences*, 91(4), 563-567.
- Ghosh, S. (2020). Operational longevity and the role of angel investors in Indian startups. *Journal of Entrepreneurship and Management*, 9(2), 22–35.
- Goswami, N., Murti, A. B., & Dwivedi, R. (2023). Why do Indian startups fail? A narrative analysis of key business stakeholders. *Indian Growth and Development Review*, 16(2), 141-157.
- Iyappan, A., & Rajamohan, S. (2020). Building entrepreneurial eco system in India: An agripreneurship perspective. *International Journal of Advance Research in Computer Science and Management Studies*, 8(10).

- Kamilaris, Andreas, Andreas Kartakoullis, and Francesc X. Prenafeta-Boldú. "A review on the practice of big data analysis in agriculture." *Computers and electronics in agriculture* 143 (2017): 23-37.
- Kaur, A., Randhawa, G. S., Abbas, F., Ali, M., Esau, T. J., Farooque, A. A., & Singh, R. (2024). Artificial intelligence driven smart farming for accurate detection of potato diseases: A systematic review. *IEEE Access*, 12, 1–18.
- Korreck, S. (2019). *The Indian startup ecosystem: Drivers, challenges and pillars of support* (ORF Occasional Paper No. 210). Observer Research Foundation.
- Li, C., Ahmed, N., Qalati, S. A., Khan, A., & Naz, S. (2020). Role of business incubators as a tool for entrepreneurship development: the mediating and moderating role of business start-up and government regulations. *Sustainability*, 12(5), 1822.
- Liakos, Konstantinos G., Patrizia Busato, Dimitrios Moshou, Simon Pearson, and Dionysis Bochtis. "Machine learning in agriculture: A review." *Sensors* 18, no. 8 (2018): 2674.
- Mason, C., & Brown, R. (2014). Entrepreneurial ecosystems and growth oriented entrepreneurship. *Final report to OECD, Paris*, 30(1), 77-102.
- Mhlanga, N. (2023). Infrastructure and policy challenges in digital agriculture in Africa. *FAO Report Series*.
- Mitra, S., Kumar, H., Gupta, M. P., & Bhattacharya, J. (2023). Entrepreneurship in smart cities: elements of start-up ecosystem. *Journal of Science and Technology Policy Management*, 14(3), 592-611.
- Munshi, S. (2019). *Start-ups: Transforming India's food processing economy*. FICCI & YES BANK.
- Nam, J., Jung, Y., & Kim, J. (2024). Understandings of the AI business ecosystem in South Korea: AI startups' perspective. *Telecommunications Policy*, 48(6), 102763.
- Nuthalapati, C. S., & Nuthalapati, C. (2021). Has Open innovation taken root in India? Evidence from startups working in food value chains. *Circular Economy and Sustainability*, 1(4), 1207-1230.
- Raj, S., Raahalya, S., & Anand, A. (2024). Fostering innovations in agriculture: an analysis of agri-startups and stakeholders' engagement. *International Journal of Agriculture Innovation, Technology and Globalisation*, 4(4), 301-333.

- Rao, S. R., & Kumar, L. (2016). Role of angel investor in Indian startup ecosystem. *FIIB Business Review*, 5(1), 3-14.
- Sadjadi, A., & Fernández, I. (2023). AI and IoT in climate-resilient agriculture. *Journal of Smart Farming*, 4(1), 23–41.
- Saqib, N., & Shah, G. B. (2023). Business model innovation through digital entrepreneurship: A case of online food delivery start-up in India. *International Journal of E-Entrepreneurship and Innovation (IJEI)*, 13(1), 1-20.
- Scillitoe, J. L., & Birasnav, M. (2022). Ease of market entry of Indian startups: formal and informal institutional influences. *South Asian Journal of Business Studies*, 11(2), 195-215.
- Senoo, T., Yamada, Y., & Okabe, K. (2024). Blockchain and AI for food traceability. *Computers and Electronics in Agriculture*, 207, 107725.
- Sharma, R., Kamble, S. S., & Gunasekaran, A. (2018). Big GIS analytics framework for agriculture supply chains: A literature review identifying the current trends and future perspectives. *Computers and Electronics in Agriculture*, 155, 103-120.
- Singh, S. (2016). *Financial challenges of Indian startups and government initiatives*. ADBI Working Paper Series No. 560. Asian Development Bank Institute.
- Singh, S., Chauhan, A., & Dhir, S. (2020). Analyzing the startup ecosystem of India: a Twitter analytics perspective. *Journal of Advances in Management Research*, 17(2), 262-281.
- Srishailam, B., Sailaja, V., Nikhitha, A., & Kiran, P. K. (2022). Promoting start-ups in agriculture: An innovative approach for transforming agriculture to agri-business. *Vigyan Varta*, 3(4), 73-81.
- Subash S P, Srinivas K, Samuel M P and Kalpana Sastry R. 2016. Evolution of agribusiness incubation ecosystem in NARES for promoting agri entrepreneurship. *Indian Journal of Agricultural Economics* 71(3): 237–51.
- Vijayan, B., & Shivkumar, P. S. (2020). Pro-agripreneurial Factors for the Formation of Agri-startups in India. *Asian Journal of Agricultural Extension, Economics & Sociology*, 38(8), 1-8.
- Wolfert, Sjaak, Lan Ge, Cor Verdouw, and Marc-Jeroen Bogaardt. "Big data in smart farming—a review." *Agricultural systems* 153 (2017): 69-80.

Yuan F, Ospina R, Perumal AB, Noguchi N, He Y, Liu Y. Smart agriculture in Asia. Plant Commun. 2025 Jul 14;6(7):101377. Doi: 10.1016/j.xplc.2025.101377. Epub 2025 May 15. PMID: 40380769; PMCID: PMC12281225.

<https://www.fao.org/climate-smart-agriculture/policies-planning/en/>

<https://farmonaut.com/asia/agriculture-policy-of-india-2025-strategies-creation>

<https://indiaai.gov.in/article/ai-in-agriculture-in-2025-transforming-indian-farms-for-a-sustainable-future>

<https://sustainablefinancecenter.org/sustainable-and-climate-smart-agriculture-finance-in-india-indias-policy-financing-and-opportunity-for-action/>

<https://www.ibm.com/think/topics/smart-farming>



NATURALLY COLOURED COTTON: A SUSTAINABLE FIBRE IN A RAPIDLY EXPANDING GLOBAL TEXTILE LANDSCAPE

Article ID: AG-VO5-I12-146

***A R Priyanka¹ and Ramya K R¹**¹ICAR – Central Institute for Cotton Research, Regional Station, Coimbatore – 3, TN, India

*Corresponding Author Email ID: priyankarajendran28@gmail.com

Introduction

Global fibre production has expanded dramatically over the past two decades, increasing from about 58 million tonnes in 2000 to more than 109 million tonnes by 2020, with continued growth expected as population size, consumption patterns, and textile demand rise worldwide. Within this expanding fibre economy, cotton remains the most widely used natural plant-based fibre, serving as a cornerstone of the global textile and apparel industry. Cotton fibres are unicellular epidermal outgrowths of the seed coat produced by domesticated species of the genus *Gossypium*, and they possess unique characteristics of softness, breathability, and versatility that make them indispensable for textile manufacturing. However, the environmental footprint of conventional cotton textiles—particularly the bleaching and synthetic dyeing stages—has raised significant concerns due to high water consumption, energy use, and discharge of chemically hazardous effluents. These environmental challenges have renewed scientific and commercial interest in naturally coloured cotton as a sustainable alternative.

Concept and Significance of Naturally Coloured Cotton

Naturally coloured cotton, often referred to as eco-friendly cotton, produces fibres with inherent pigmentation, eliminating or greatly reducing the need for chemical dyeing. Unlike conventional white cotton, which requires extensive chemical processing to achieve desired colours, coloured cotton derives its hues directly from genetically regulated pigment accumulation during fibre development. Naturally occurring fibre colours include shades of brown, green, tan, red, and mocha, primarily observed in tetraploid cotton species. While *Gossypium hirsutum* typically produces white lint, certain genotypes exhibit brown and green

fibres, whereas *G. barbadense* may show cream or tan shades. These variations reflect complex biochemical and genetic processes that regulate pigment biosynthesis within the fibre cell.

Historical Origin and Domestication of Coloured Cotton

Coloured cotton is not a recent innovation but rather a rediscovered heritage crop. Archaeological evidence indicates that naturally pigmented cotton was cultivated and utilized as early as 2500–3000 BCE in ancient civilizations such as the Indus Valley, Peru, and Egypt. These early societies valued coloured cotton because its natural hues allowed direct weaving without the need for dyeing. In South America, particularly along the Peruvian coast, brown and cream-coloured *G. barbadense* fibres have been recovered from burial sites, highlighting advanced textile traditions and early domestication of pigmented cotton. Similarly, early Indian communities cultivated coloured forms of *G. arboreum*, producing brown and reddish fibres well suited for hand spinning and traditional weaving. During periods of material scarcity, such as World War II, naturally coloured cotton regained temporary importance due to shortages of dyeing chemicals. However, with the rise of industrial textile production in the 18th and 19th centuries, white cotton became dominant because it allowed uniform bleaching and dyeing, leading to the marginalization of coloured cotton in commercial agriculture.

Diversity of Coloured Cotton Species and Fibre Types

Scientific interest in coloured cotton re-emerged in the late 20th century alongside growing awareness of textile-related environmental pollution. Breeding initiatives in countries such as the United States, China, and India focused on improving fibre quality, colour stability, and yield while maintaining pigmentation traits. Pioneering work by breeders, notably Sally Fox in the early 1980s, demonstrated that natural colour and acceptable fibre quality could be combined, paving the way for renewed commercialization. Today, coloured cotton occupies a unique position at the intersection of traditional knowledge and modern sustainable agriculture.

Genetic Basis of Fibre Colouration in Cotton

The genetic basis of fibre colour in cotton is primarily associated with the accumulation of pigments such as anthocyanins, proanthocyanidins, and related phenolic compounds synthesized through the phenylpropanoid and flavonoid pathways. Brown fibre coloration is largely attributed to proanthocyanidins, also known as condensed tannins, whereas red and purple hues arise from anthocyanin derivatives. Green fibre pigmentation, in contrast, appears to involve a more complex biochemical profile, including flavonoids, caffeoyl-derived compounds,

and lignan-related metabolites. The synthesis of these pigments is tightly regulated by coordinated gene networks, particularly transcription factors belonging to the MYB, bHLH, and WD40 families, which activate structural genes in the flavonoid biosynthetic pathway.

Biochemical Basis of Pigmentation in Coloured Cotton

At the biochemical level, enzymes such as chalcone synthase, chalcone isomerase, flavanone 3-hydroxylase, flavonoid 3'-hydroxylase, and flavonoid 3'5'-hydroxylase play central roles in determining pigment composition and intensity. These enzymes catalyze sequential reactions that convert phenylalanine-derived precursors into diverse anthocyanidin compounds, including pelargonidin, cyanidin, and delphinidin, which collectively generate a spectrum of fibre colours. Studies have shown that brown fibre genotypes exhibit higher expression of key flavonoid pathway genes, leading to enhanced pigment deposition compared with white fibre lines. The timing and magnitude of pigment accumulation during fibre development are also critical determinants of final colour expression.

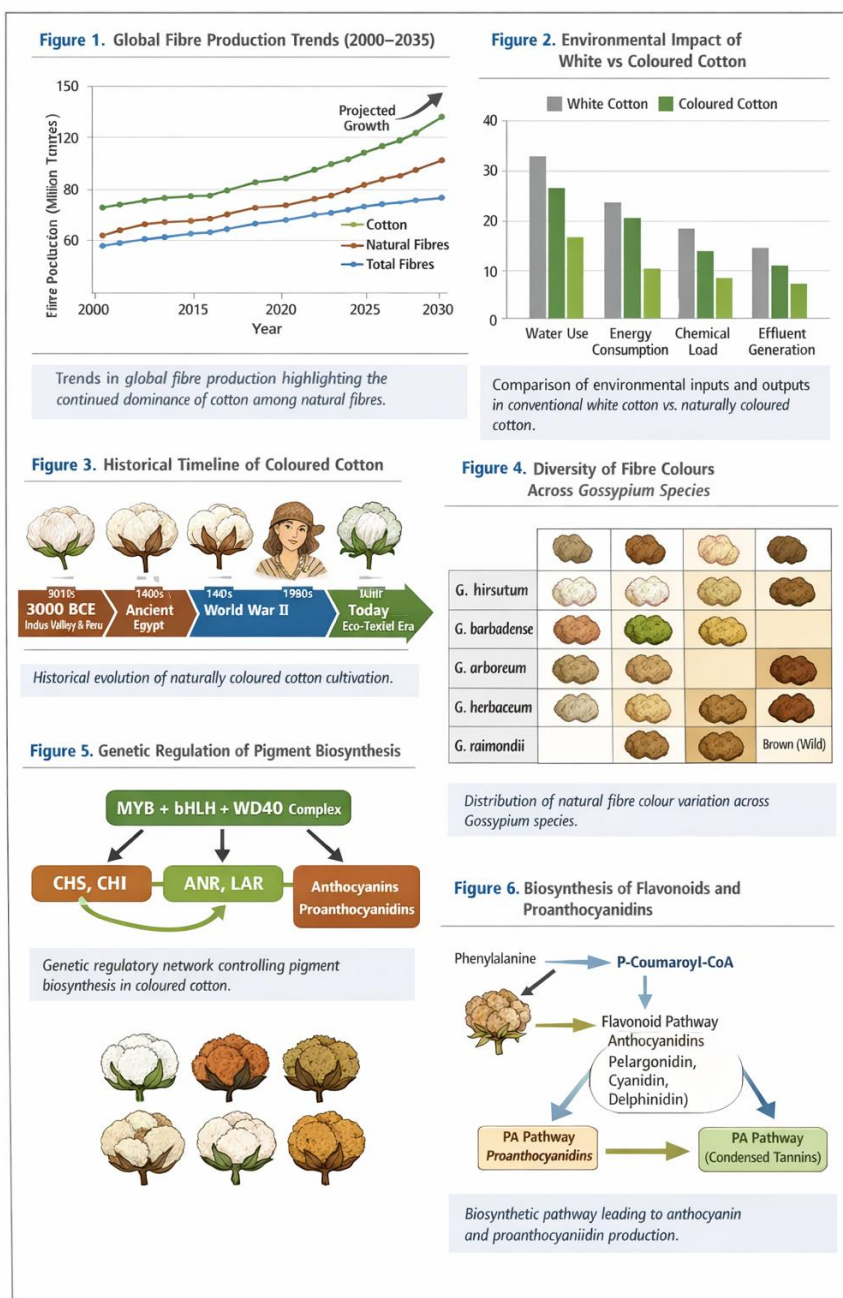
Pigment Composition in Brown Cotton Fibres

Proanthocyanidins, the principal pigments in brown cotton fibres, accumulate in a developmentally regulated manner. In white cotton fibres, only trace levels of these compounds are detected during early stages of fibre growth, followed by a gradual decline. In contrast, brown fibres begin accumulating proanthocyanidins as early as three days post-anthesis, with concentrations increasing steadily until maturity. Structurally, these pigments consist of polymerized flavan-3-ol units arranged in a diphenylpropane framework, conferring chemical stability and contributing to the durable brown coloration observed in mature fibres. Green cotton fibres, meanwhile, display a distinct pigment profile. While early studies emphasized flavonoids as the dominant pigments, subsequent metabolic and proteomic analyses revealed the involvement of caffeoyl-containing compounds and lignan biosynthesis, suggesting that green fibre pigmentation arises from multiple overlapping biochemical pathways.

Environmental Influence on Pigment Accumulation

Environmental factors exert a strong influence on pigment biosynthesis in naturally coloured cotton. Light intensity, temperature, and water availability can significantly alter metabolic flux through the flavonoid and proanthocyanidin pathways, affecting colour intensity, uniformity, and stability. Variations in these environmental conditions may enhance or suppress pigment accumulation, resulting in observable differences in fibre hue across growing seasons

and locations. Understanding these genotype–environment interactions is essential for stabilizing colour expression under diverse agro-climatic conditions.



From an environmental and economic perspective, naturally coloured cotton offers substantial advantages over conventionally dyed textiles. Because the fibres do not require bleaching or synthetic dyeing, coloured cotton can reduce dyeing costs by up to 50 percent while significantly lowering water use, energy consumption, and the release of toxic dye effluents. Dyeing alone accounts for a considerable share of the environmental footprint and production

cost of finished textile products, making coloured cotton an attractive material for sustainable and circular textile systems. As global demand for environmentally responsible fibres increases, naturally coloured cotton is gaining recognition as a viable component of organic and eco-textile markets.

Coloured cotton offers important environmental and ecological advantages by eliminating or significantly reducing the need for chemical dyes during textile processing, thereby lowering water consumption, energy use, and discharge of toxic effluents into aquatic ecosystems. The natural pigmentation in fibres, mainly derived from flavonoids and proanthocyanidins, also improves biodegradability and reduces microplastic pollution when compared with synthetic-dyed textiles. Current research on coloured cotton is increasingly focused on understanding the genetic and molecular regulation of pigment biosynthesis, improving fibre quality traits through conventional breeding and genomic approaches, and enhancing colour stability without compromising yield. Advances in genomics, transcriptomics, and genome editing tools are being explored to overcome historical limitations such as lower lint yield and inferior fibre strength. Looking ahead, the future of coloured cotton depends on successfully balancing environmental sustainability with economic viability, as challenges remain in achieving consistent colour expression, improving agronomic performance, and scaling production to meet industrial demand. Nevertheless, growing consumer preference for eco-friendly textiles, supportive sustainability policies, and continued scientific innovation position coloured cotton as a promising component of climate-resilient and circular textile systems.

Conclusion

In conclusion, naturally coloured cotton represents a convergence of ancient agricultural heritage and modern sustainability science. Although challenges remain in improving fibre quality, yield, and colour stability to match elite white cotton cultivars, advances in genetics, biochemistry, and breeding have substantially enhanced its potential. By reducing chemical inputs, conserving resources, and enabling cleaner textile production, coloured cotton holds significant promise as a sustainable fibre for future agriculture and environmentally conscious textile industries.

AgriGate Editorial Team



December 2025 | Vol. 05 | Issue No. 12

Founder & Managing Director : **Mrs. Priya V**

Editor-In-Chief : **Dr. R. Shiv Ramakrishnan**

International Advisor : **Prof. Chittaranjan Kole**

Executive Editors : Dr. Sivalingam Elayabalan
Dr. Muthusamy Ramakrishnan
Mr. Srinath Balasubramanian

Editorial Manager : Dr. R. Vinoth

Editorial Advisor : Dr. G. Selvakumar

Senior Editor : Dr. K. Subrahmaniyan
Dr. N. Venkatesa Palanichamy
Dr. R. Kalaiyarasi
Dr. M. Baskar

Editors : Dr. L. Pugalendi
Dr. M. L. Dotaniya
Dr. S. Easwaran
Dr. L. Allwin
Dr. A. Thanga Hemavathy
Dr. S. Rathika
Dr. S. Srividhya
Dr. M. Dhandapani
Dr. M. Vengateswari
Dr. G. Sathish
Dr. P. Preetha
Dr. C. Sellaperumal
Dr. S. Kavitha
Dr. R. Pravallika sree
Dr. P. Reddy Priya
Dr. M. Paramasivan
Dr. S. Murali
Dr. S. Subash
Dr. Andukuri Raj Shravanthi
Dr. K. Elanchezhyan
Mr. R.C. Karthikeyan
Mr. V. Kabilraj

Media Managers



AgriGate

GROW WITH EVERY PAGE!

An International Multidisciplinary Monthly e-Magazine

Inviting Popular Articles for January Issue 2026

Dear Authors,

We are inviting Technical Article, Popular Article, Farmer Success Stories, and Short Communications from various disciplines of Agriculture and Allied Sciences in English Language.

- Agriculture & Horticulture
- Agribusiness Management
- Agricultural Engineering and Precision Farming
- Agronomy and Agricultural meteorology
- Agrl. Extension and Agrl. Economics
- Bio-Sciences / Life-Sciences
- Biotechnology & Bio-chemistry
- Environmental Science & Forestry
- Fisheries & Animal Sciences
- Food & Dairy Technology
- Genetics & Plant Breeding
- Nematology & Nano-Technology
- Organic Farming and Sericulture
- Plant Pathology & Entomology
- Seed Science & Technology
- Soil Science

Send your articles to agrigatepublish@gmail.com

Deadline for submission of articles – 15th January, 2026)

“Limit the Articles to 6-7 Pages”



[agrigatemagazine](https://www.instagram.com/agrigatemagazine)



agrigatemagazine@gmail.com



AgriGate



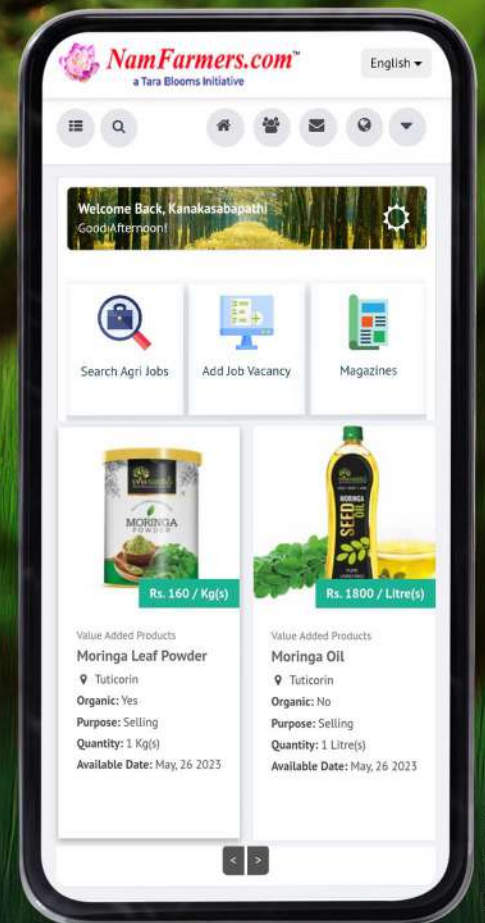
NamFarmers.comTM

a Tara Blooms Initiative

Open gate for

AGRO PRODUCTS

Let's market globally



GET IT ON
Google Play



Available on the
App Store