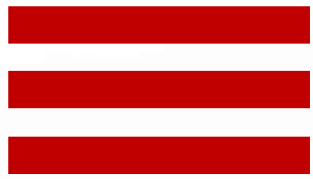
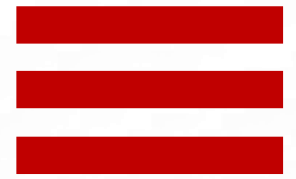


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# Nano Magic for Greener Crops: How Nano-biotechnology Revolutionizing Agriculture

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Green nano-biotechnology is emerging as a paradigm shift in sustainable agriculture, integrating plant-derived biodegradable nanomaterials to address critical challenges such as water scarcity, soil infertility, pest resistance, erratic climate patterns, and excessive chemical fertilizer/pesticide use, which lead to environmental degradation and biodiversity loss. Unlike conventional nanotechnology, green approaches minimize ecological footprints through eco-friendly synthesis methods, enabling precise, targeted delivery systems that enhance crop productivity, nutrient uptake, stress tolerance, and socioeconomic viability while curbing pollution. Overall, nano-biotechnology represents a transformative solution for developing climate-resilient, resource-efficient, and environmentally sustainable agricultural systems capable of meeting future food security demands.

## Introduction

Agriculture is the foundation of the worldwide food supply and plays a vital role in sustaining economic growth and stability. However, a multiplicity of challenges, including water scarcity, pest resistance, soil infertility, and the misuse of chemical fertilizers and pesticides, threaten the sustainability of agriculture. Extreme climate change patterns and erratic rainfall further exacerbate these challenges. Traditional agricultural methods often produce ecological imbalances and biodiversity loss, leading to environmental degradation. In this context, green nano-biotechnology is emerging as a transformative technology for sustainable agriculture. Green nano-biotechnology is an alternative to traditional nanotechnology, utilizing plant-derived resources and biodegradable polymers with a less ecological footprint and more sustainable techniques. Nano-enabled tools and formulations offer innovative solutions to improve crop productivity while supporting environmental sustainability and socioeconomic development. Nano-biotechnology can enhance plant resistance to pests and environmental stress, and improve the performance of seeds and fibers. Moreover, nano-formulated fertilizers and pesticides enable reduced application

rates through controlled, targeted delivery, thereby minimizing the environmental impact associated with excessive chemical use. The application of green nano-biotechnology spans crucial aspects such as nano-enhanced fertilizers, controlled-release herbicides, and nano-sensors for real-time monitoring. Unique properties of nano-fertilizers, such as controlled release and increased surface area, improve plant nutrient uptake and are advantageous over chemical fertilizers due to their lower environmental impact. Similarly, the enhanced reactivity of nano-pesticides often tailors pest control mechanisms by protecting pollinators or selectively killing target organisms. Additionally, nano-biosensors contribute to precision agriculture by tracking soil moisture and nutrient levels, enabling farmers to make data-driven decisions to optimize resource use and increase crop productivity.

## Nano-fertilizers:

Nano-fertilizers are synthesized or modified forms of traditional fertilizers produced using nanotechnology, converting bulk materials into nanoparticles less than 100 nm in size via chemical, physical, mechanical, or biological methods.



**Need for Nano-fertilizers:**

Conventional fertilizers cause environmental pollution, low efficiency, soil degradation, and nutrient imbalances. In India, the current NPK (Nitrogen, Phosphorus, Potassium) ratio is about 10:2.7:1, whereas the recommended ratio is 4:2:1. This imbalance contributes to stagnant yields and 25–30% crop losses, mainly due to widespread nitrogen (89%) and phosphorus (80%) deficiencies. Nano-fertilizers offer the Green Revolution by providing precise nutrient delivery, reducing overuse, and supporting a Second Green Revolution for feeding 1.4 billion by 2030.

**Impact on Plant Growth:**

Nano-fertilizers are outperforming conventional fertilizers due to their large surface area, chemical reactivity, water-adsorption capacity, and rapid dispersibility. It slows down the release of nutrients, which significantly influences the Nitrogen Use Efficiency (NUE) - a crucial indicator of crop yield. When applied to soil, Nano-fertilizers first come in contact with plant roots and promote growth by facilitating the uptake of essential nutrients. In wheat, millet, and cotton, nano-fertilizers contribute to the breakdown of carbohydrates, the release of plant hormones, and the synthesis of Indole-Acetic-Acid. It boosts chlorophyll content and improves the plant's capacity to absorb sunlight, Rubisco activity, CO<sub>2</sub> metabolism, and photosynthetic efficiency. Additionally, Nano-fertilizers stimulated Nitrogen and Phosphorus assimilation, facilitated Reactive Oxygen Species detoxification, and enhanced Photo-reduction activity in Photosystem II and the Electron Transport Chain.

**Impact on Seed Germination:**

Nano-fertilizers have a significant impact on seed germination and seedling growth. Because of their easy penetration, nano-fertilizers make nutrients more available to seedlings, helping them grow healthier with longer roots and shoots.

**Higher Nutrient Use Efficiency:**

Due to their small particle size, nano-fertilizers exhibit a higher surface area, making more sites accessible to various plant metabolic processes and thereby promoting photosynthesis. Nano-fertilizers can more readily enter plant systems due to their small particle size and large surface area, thereby improving nutrient uptake and utilization through soil or leaves. Moreover, fertilizers encapsulated in nanoparticles enable the gradual release of nutrients, providing a steady supply to crops, and help prevent nutrient loss through volatilization, denitrification, fixation, and leaching.

**Nano-pesticide:**

Nano-pesticides are advanced crop protection formulations that use nanoscale materials to enhance delivery, stability, and effectiveness while minimizing environmental and human health risks.

**Need for Nano-pesticide:**

Nano-pesticides contribute to more sustainable agricultural practices by improving active ingredient delivery, enhancing solubility, and facilitating controlled release over time. Nano-pesticides provide improved penetration, adhesion, and site-specific action, with minimal effect on beneficial organisms, and are advantageous over traditional pesticides, which suffer from leaching and volatilization. Chemical pesticides contaminate water, soil, and air, leading to bioaccumulation. Nano-pesticide addresses this concern by reducing the overall chemical load. Their controlled-release mechanism enables sustained pesticide delivery with a minimal ecological footprint. The most promising application of Nano-pesticide over traditional pesticides is that they can be functionalized with molecular markers to specifically target pests without harming pollinators and natural predators. Nano-pesticides with their sustained-release mechanism ensure that pests are consistently exposed to sub-lethal doses of pesticide, thereby reducing the likelihood of resistance



development and helping mitigate pest-induced damage and the risk of crop loss.

But the selection of Nano-pesticides should consider the following points

- Easy to prepare
- Economically viable
- Effective over a wide range of pests
- Non-toxic
- Should not accumulate in the food chain

### **Mechanism of Action:**

#### **1. Enhanced targeting and penetration:**

Nano-pesticides can penetrate the cuticle and plant cell wall more easily. For instance, mesoporous and polymeric silica nanoparticles improve the stability and solubility of hydrophobic pesticides, enhancing their uptake through plant roots and leaves. This facilitates systemic movement within the plants, increasing their effectiveness against hidden pests and diseases. Nanocarrier systems, such as silica-based formulations, have been reported to enhance foliar uptake of pesticides, thereby promoting improved translocation and prolonged retention within plant tissues. This is crucial for effective management of piercing-sucking insects that feed on plant sap.

#### **2. Controlled release of sustained activity:**

Controlled, sustained release of pesticides over time ensures continuous pest protection without the need for frequent applications, with reduced environmental contamination and leaching into groundwater.

#### **3. Multifunctional Nano-pesticide:**

Some nano-pesticides are engineered with dual or even multiple functions. For example, certain nano-pesticides are designed to carry both fungicide and insecticide simultaneously, allowing a single application to target multiple pests. Additionally, some are designed with UV protection features, thereby helping prevent degradation of the active

ingredient when exposed to sunlight and maintaining prolonged efficacy in the field.

### **Nano-biosensor:**

Nano-biosensors have diverse applications in agriculture, enabling the detection and monitoring of fertilizers, herbicides, pesticides, insecticides, soil moisture, and pH levels. When integrated with precision farming systems, these smart sensing devices improve nutrient management, optimize input utilization, lower production costs, and reduce environmental impact. Nano-sensors can also identify plant viruses, soil nutrient status, and crop pathogens, thereby supporting timely, targeted interventions.

Precision agriculture strategies based on nano-sensor technology enhance the efficient use of essential resources such as water, nutrients, and agrochemicals. Additionally, nano-sensors enable rapid, accurate detection of bacterial and viral contaminants, thereby improving food safety and quality assurance.

Electrochemically functionalized single-walled carbon nanotube (SWCNT)-based nano-sensors, often coupled with metal or metal oxide nanoparticles, are particularly effective in detecting agricultural gases such as ammonia, nitrogen oxides, hydrogen sulphide, sulphur dioxide, and volatile organic compounds. These systems are valuable for monitoring environmental pollutants, assessing their effects on living organisms, and supporting improvements in crop productivity.

Innovative applications have even demonstrated the transformation of plants, such as spinach, into living sensing platforms capable of transmitting infrared signals in response to environmental stimuli, thereby functioning as biological auto-samplers that communicate real-time information about their surroundings.



### Challenges and Safety Considerations

Despite its promising potential, nano-biotechnology must be adopted cautiously. Key challenges include:

- Standardization of nano-formulations
- Assessment of long-term environmental impact
- Regulatory frameworks for nano-based agricultural inputs
- Cost-effective large-scale production
- Farmer awareness and field-level validation
- Scientific evaluation of nanoparticle toxicity, persistence, and interaction with soil microbiota is essential to ensure safe deployment.

Responsible innovation, transparent regulatory policies, and interdisciplinary collaboration are crucial for mainstream adoption.

### Future Prospects

The future of agriculture lies in integrating biological wisdom with technological innovation. Nano-biotechnology represents a convergence of material science, plant physiology, microbiology, and environmental engineering. Its applications in nutrient management, stress mitigation, crop protection, and post-harvest technology demonstrate immense potential to address global food security challenges.

Research efforts are increasingly focusing on biodegradable nanomaterials, carbon-based

nanostructures, nano-enabled gene delivery systems, and nano-bio interfaces that enhance plant–microbe interactions. As scientific understanding advances, nano-biotechnology could play a pivotal role in developing resilient cropping systems tailored to diverse agro-climatic conditions.

### Conclusion

Nano-biotechnology is not merely a technological advancement; it is a paradigm shift toward more innovative, safer, and more sustainable agricultural systems. By improving input efficiency, reducing environmental footprint, and enhancing crop resilience, it offers practical solutions to some of the most pressing challenges facing modern agriculture.

For sustainable agricultural development, integrating eco-friendly nanotechnology with traditional agronomic practices, farmer education, and supportive policy frameworks will be essential. With responsible innovation and scientific rigor, nano-biotechnology can become a new frontier in building a cleaner, healthier, and more productive agricultural future.

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# Pear its Training, Pruning and Planting after Care of Pear

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Pear (*Pyrus communis* L.), belonging to the family Rosaceae, is one of the most widely cultivated and consumed temperate fruits across the globe. Pears belong to the genus *Pyrus* in the Rosaceae family. These deciduous trees or shrubs produce pomaceous fruits typically with a distinctive bell shape rounded at the base and tapering toward the stem. With origins in temperate regions of Europe, North Africa, and Asia, there are over 3,000 cultivated pear varieties worldwide, primarily classified into European (*P. communis*) and Asian (*P. pyrifolia*) types. According to FAO data, global pear production reached approximately 26.3 million tonnes in 2022, with China contributing around 73% of this total (~19.3 Mt), followed by countries like the USA, Argentina, and Italy. In India, pear is mainly grown in temperate and subtropical zones—Punjab, Jammu & Kashmir, Uttarakhand, and Himachal Pradesh being key regions. Cultivars are selected based on chilling requirements, ranging from high-chill varieties in the Himalayas to low-chill types like Patharnakh on the plains. The area under cultivation has grown from ~19,000 ha in 1991 to ~42,000 ha by 2019, with India producing roughly 280,000 tonnes annually, ranking among the top 10 pear-producing nations worldwide.

## Introduction

Pears are nutrient-dense yet low in calories (100 kcal per medium fruit) and zero in fat and cholesterol. A medium pear typically contains: Dietary fiber: 5.5–6 g (20–22% of daily needs), Vitamin C: ~8–9 mg (~9% Daily Value), Vitamin K: 7–8 µg (~7% DV), Potassium: 200 mg – 4% DV, Copper: 16% DV; along with contributions of folate, B complex vitamins, and antioxidants like anthocyanins and flavonoids. Pears offer both soluble and insoluble fiber (about 71% insoluble, 29% soluble) and a notable content of polyphenols, mainly concentrated in the skin- up to 6–20 times higher than the flesh. The fruit also contains natural sugars—fructose, glucose, sucrose, and sorbitol—with fructose and sorbitol being particularly abundant. Pear is a species of genus *Pyrus* belonging to the family Rosaceae and subfamily Pomoideae. In terms of importance, area, production and varietal diversity, pears are second only to apples, as a most significant temperate fruit crop farmed throughout the world's temperate areas (Mitra et al., 1991).

China is the major producer of pear in the world along with Italy, USA, Germany, Argentina, Turkey and South Africa. In India pear cultivation is mainly confined to the temperate Himalayan mountains which have ideal conditions to grow a large number of European (*Pyrus communis* L.) and Oriental [*Pyrus pyrifolia*(Burm.) Nakai] pear. However, selection and development of low chill pear cultivars and hybrids of European and Oriental pears had made its cultivation possible in subtropical regions of Uttar Pradesh, Punjab, Haryana and Uttarakhand which receives sufficient amount of cold winters, necessary for meeting chilling requirement and mild temperature suitable for flowering and better fruit set (Janick, 1991). In India, pear is occupying an area of 43.0 thousand ha with an annual production of 306.0 thousand MT (Anonymous, 2019). Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab and Tamil Nadu are the states that produce the majority of pears. Uttarakhand ranks 1st in the country in production of pear with an area of 13.0 thousand ha, annual production of 78.8 thousand MT (Anonymous,



2020). Pear is a good source of minerals, nutrients, dietary fiber and health promoting bioactive compounds such as carotenoids (flavonols, anthocyanins, kaemferol and isorhamnetin) and phenolic compounds (Salta et al., 2010 and Verma and Kushwaha, 2018). In pear the TSS and acidity ranges from 12.9 to 17.2 per cent and 0.23-0.44 per cent, respectively, while the average fruit weighs between 110 and 205 g and has a juice content of 43.6 to 59.7 per cent (Ghosh et al., 2015). It is often less winter-hardy than apples and is therefore more restricted to climates without harsh winters, although due to their wider climatic and soil adaption, pear can be grown in temperate and subtropical climates in India. It can withstand temperatures as low as  $-26^{\circ}\text{C}$  during the dormant season and as high as  $45^{\circ}\text{C}$  during the growing season. High chilling varieties are primarily grown in Himachal Pradesh, Jammu and Kashmir and Uttarakhand on hills between 1700 and 2400 metres above mean sea level. Low chilling pears have thrives in subtropical climates (Chadha, 2019).

### Planting and After Care

The optimal period to plant pear trees is from the middle of January to the first fortnight of February, before they begin to sprout new growth. Plants that are at least a year old and in good health should be utilised for planting. With good results, older plants that are 2-3 years old can also be planted. Before the plants are put in the field, the orchard site should be properly laid out. The trees may be planted at a distance of about 7.5 metres apart by which 180 plants are accommodated in one hectare by the square system of planting. The hexagonal technique, which allows 207 plants to be planted in a hectare, is another option for planting pears. Pear can also be placed 5 x 5 metres apart. Using quince rootstock, high density planting pear have been attempted. Planting distance of 3-3.5 x 1.2 m on Quince MA has been recommended for William's Basins should be prepared immediately after planting. The level of soil near the trunk should be kept slightly higher than the level of basins so that water may not come in direct contact of the trunk. Irrigation should be given immediately after planting

so that soil may settle down properly around the roots. After two or three days, second irrigation should be given. Subsequent irrigations should be given as and when required. The irrigation interval up to March may be 15-20 days, but later on as the season warms up the interval may be reduced to 10-12 days up to June. Irrigation during rainy season is not required. The trunk of young plants should be white washed once in March, again in May and then in the rainy season to avoid injury from sun-burn and to prevent cracking of bark Farmyard manure should be mixed in the basins at the rate of 20 kg per tree in January-February, Irrigation should be applied immediately after it is thoroughly mixed in the basins. To check the attack of white ants, the trees should be given chlorpyrifos 2 ml per litre of water once in April and then after rains. The surplus shoots not required for building the framework of the trees should be removed. The shoots appearing on the rootstock should also be removed, otherwise they will have an adverse effect on the growth of plants. Trees should be protected from insect and pests by following the proper spraying schedule.

### Orchard Cultural Practices Training and Pruning

Proper training and pruning of pear trees is essential for the development of proper framework and to control the size of the tree for the convenience of horticultural operations, to maintain the vigour and growth of the tree, to spread the fruiting area uniformly on the tree, to secure fruit of Pear good size and quality and to encourage regular bearing. Pear trees can be trained according to modified leader system, free standing, pyramid, spindle bush, palmette and tatura trellis. For high density planting, tatura trellis system of training is followed. Typically, pears are trained using the modified leader method.



Figure. pruning in pear



**Training in the first year:** In low-headed trees, the lowest branch is allowed to develop up to a height of 60 cm and accordingly top the plant is cut at about 90 cm. If high-headed trees are required, then the plant should be headed back at a height of 12 to 1.5 metres.

**Training in second year:** The largest shoot in the centre is kept as the leader, the beginning of the immature area is clipped back. Three to five laterals (major scaffold branches), spaced 15 to 22 cm apart, are maintained in various directions. By attaching these laterals to the ground with rope or thick thread, it is preferable to bend them downward. These laterals will be tied, which will promote the growth of secondaries.

**Training in 3-4 year old trees:** One or two of the new laterals that arise when the second season's growth is complete from the laterals left over should be chosen to build the secondary scaffolds framework. The laterals should be directed backward to promote the sprouting of buds that will give rise to tertiary branches.

**Training in 5 year old trees:** To an appropriately situated, outward-going lateral, the leader should now cut back.



*Figure. old orchard pear*

**Pruning of young bearing trees:** Pear trees produce fruit on spurs, or stems with restricted growth. These spurs only grow a few millimetres per year yet produce fruit for 8–10 years. Consequently, for the first 10 years, only corrective pruning is done on young trees. Just cut off diseased, dry, and

encroaching branches. Extreme pruning, which would result in the loss of fruiting spurs, should not be done during this time. When picking fruit, caution should be used to prevent injury to the spurs.

**Pruning of older trees:** The bearing wood of the elder trees needs to be rejuvenated and regenerated. The largest branches are completely removed to achieve this. To allow more light and greater colour, this helps to open up the trees. The renewal process takes 3 to 4 years to complete in stages. The trees once more sprout new fruiting spurs, which continue to produce fruit for an additional ten years. In early February or in January, pear pruning should be carried out.



**Rejuvenation of old pear orchards.** Around 20 years of age is when pear trees start to become less fruitful. Such trees can be revived to resume production. That can be accomplished by repositioning the three to four major scaffolds back by about 15 cm in the months of December and January. Remove all of the remaining scaffolds. Bordeaux paint should be applied to the cut edges. In March, the majority of the sprouts on these stubs will appear. Just one to two outgoing shoots from each stub should be kept in May, for a total of six to eight shoots per tree. Rejuvenated trees begin bearing fruit in their third year and produce a commercial crop in their fifth year.

# Sustainable Management of Crop Residues

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Crop residue burning has emerged as one of the most persistent challenges in Indian agriculture, drawing attention not only for its contribution to air pollution but also for its long-term impact on soil health, crop productivity and climate change. Crop residues, which include stalks, stubbles, straw, leaves and processing by-products such as husks, bagasse and molasses, are generated in enormous quantities every year. While these residues were traditionally recycled within farming systems, intensification of agriculture and mechanised harvesting have significantly increased residue accumulation, leading to widespread burning as a method of disposal.

India generates approximately 500 million tonnes of crop residues annually, of which nearly 92 million tonnes are burned in open fields. States such as Uttar Pradesh and Punjab occupy the top positions in both crop residue production and burning, primarily due to the dominance of cereal-based cropping systems. It is estimated that more than 58 per cent of residues burned originate from cereal crops, followed by fibre crops (23%), oilseeds (7%), pulses (2%) and sugarcane (2%) (NPCMR, 2014). The rice-wheat cropping system, particularly in the Indo-Gangetic plains, is a major contributor to this problem.

## Environmental and soil impacts of residue burning

Crop residue burning is a significant source of greenhouse gas emissions. Large quantities of carbon dioxide, carbon monoxide, non-methane volatile organic compounds, particulate matter, nitrogen oxides, ammonia and sulphur oxides are released into the atmosphere. Studies have shown that farm fires contributed up to 25 per cent of PM<sub>2.5</sub> (Particulate Matter) pollution in Delhi during peak episodes, underlining their role in deteriorating urban air quality.

From an agronomic perspective, residue burning results in substantial loss of soil nutrients. Burning one tonne of rice straw leads to the loss of approximately 5.5 kg nitrogen, 2.3 kg phosphorus, 25 kg potassium and 1.2 kg sulphur, along with organic carbon. These losses directly reduce soil fertility and increase reliance on external fertiliser inputs. Moreover, the high temperature generated during burning adversely affects soil biological properties

by destroying beneficial microorganisms responsible for nutrient transformation and organic matter decomposition. Repeated burning ultimately leads to soil degradation, reduced water-holding capacity and decline in crop productivity.

## Crop residues: a valuable resource

Contrary to their perception as waste, crop residues are a valuable renewable resource with multiple agricultural, industrial and environmental applications. Sustainable crop residue management offers a viable pathway to mitigate pollution, enhance soil health and generate additional income for farmers. Crop residue management strategies can broadly be classified into on-farm and off-farm approaches.

## On-farm crop residue management

Residue removal involves collecting straw, husk and other residues from the field for alternative uses such as livestock feed, fuel or industrial raw materials. However, residue removal must be guided by



sustainable residue removal rates to avoid negative impacts on soil health. For example, studies suggest that only 30–50 per cent of corn stover can be safely removed without compromising soil organic carbon and erosion control. Removal rates should be lower in warm and humid climates, coarse-textured soils and intensively tilled systems.

Residue retention, where residues are left on the soil surface after harvest, plays a crucial role in conservation agriculture. This practice requires adoption of reduced or zero tillage systems. Technologies such as the Happy Seeder and Turbo Happy Seeder enable sowing of wheat directly into standing rice stubble without prior residue removal or burning. Residue retention improves soil physical, chemical and biological properties, enhances soil organic carbon sequestration and reduces erosion.



Happy Seeder

Surface mulching is a modified form of residue retention in which residues are chopped and evenly spread on the soil surface using a Super Straw Management System (SSMS) attached to combine harvesters. Mulching improves soil moisture conservation, increases microbial biomass carbon and soil enzyme activities, and reduces nutrient losses through runoff. However, challenges such as poor seed germination due to straw accumulation, choking of machinery and requirement of high horsepower tractors limit its widespread adoption.

Residue incorporation involves mixing crop residues into the soil using tillage implements such as mouldboard ploughs, disc harrows or rotavators. Super seeders and roto-till drills allow simultaneous incorporation and sowing. Incorporation improves soil structure and water retention but may cause

short-term nitrogen immobilisation due to high carbon-to-nitrogen ratio of residues and increased methane emissions under anaerobic conditions. Adequate decomposition time between crops is therefore essential.

Composting is an effective and low-cost on-farm residue management option. Crop residues, owing to their high organic matter content, serve as ideal raw materials for compost production. The use of microbial inoculants such as PUSA Decomposer, developed by ICAR, accelerates decomposition of paddy straw and converts residues into nutrient-rich organic manure. Compost application improves soil structure, nutrient availability and moisture retention.



PUSA decomposer

### Off-farm crop residue utilisation

Vermicomposting converts crop residues into high-quality organic fertiliser through the action of earthworms and microorganisms. Species such as *Eisenia foetida* are commonly used in India. Vermicompost enhances soil physical, chemical and biological properties, improves crop yield and reduces pest and disease incidence, although it requires careful maintenance and time.

Crop residues also constitute an important livestock feed resource. Wheat straw (bhusa) forms a basal diet for buffaloes, while rice straw can be nutritionally enhanced through fermentation and ensiling with additives such as molasses, urea and salts. However, high lignin content necessitates processing and livestock feeding contributes to methane emissions.



Biochar production from crop residues through pyrolysis at temperatures above 400°C under oxygen-limited conditions has gained attention as a climate-smart practice. Biochar acts as a long-term carbon sink, enhances nutrient retention, improves fertiliser use efficiency and reduces nutrient leaching. High production costs, however, remain a constraint.

Crop residues are increasingly used for energy generation. India's bioenergy potential from surplus residues is estimated at 4.15 EJ. Residues such as rice straw, sugarcane bagasse, maize straw and cotton stalks are utilised for electricity generation, biogas production, bioethanol and bio-oil. One tonne of crop biomass can generate approximately 300 kWh of electricity, while 382-471 litres of ethanol can be produced from one tonne of dry crop residue. Co-firing of crop residue pellets with coal in thermal power plants has also been promoted.

Residues are further utilised in mushroom cultivation, paper and packaging industries, construction materials, and production of eco-friendly consumer goods. Rice and wheat straw are widely used in pulp and paper industries, while crop residue ashes serve as partial cement replacements due to their pozzolanic properties. Ashes derived from residues such as palm oil fuel ash, rice husk ash, sugarcane bagasse ash and bamboo leaf ash can be effectively used as partial replacements for cement, reducing cement consumption and environmental impact. Coconut shells can also be utilised as aggregates in hollow bricks, where they improve structural strength while lowering material weight. In addition, agricultural residues are used in the manufacture of wood plastic composite (WPC) boards, which are durable, long-lasting materials that serve as sustainable alternatives to natural wood and plywood in construction.



WPC board



Hollow bricks

### Policies and way forward

Several national-level initiatives have been introduced to address the problem of crop residue burning through policy support, technological interventions and financial incentives. The National Thermal Power Corporation (NTPC) has advised the co-firing of crop residue pellets with coal, up to nearly 10 per cent, in thermal power plants. This initiative not only helps reduce dependence on fossil fuels and greenhouse gas emissions but also creates an assured market for crop residues, enabling farmers to earn approximately ₹5,500 per tonne of crop residue supplied for pellet production. Similarly, under the Rashtriya Krishi Vikas Yojana (RKVY), a State Plan Scheme of Additional Central Assistance was launched in August 2007 during the 11<sup>th</sup> Five-Year Plan, through which around 456 farmers in Uttar Pradesh were trained in agro-waste bio-conversion and bio-compost production, promoting value addition and sustainable residue management practices at the grassroots level.

At the national policy level, the National Policy for Management of Crop Residue (NPMCR) was launched in 2014 with the objective of providing a comprehensive framework to address crop residue burning. The policy emphasises the control of residue burning through promotion of in-situ management practices, diversification of crop residue utilisation for agriculture, energy and industrial purposes, and strengthening of capacity building and awareness among farmers and stakeholders. It also focuses on



the formulation and implementation of appropriate legal and legislative measures, development and promotion of suitable crop residue management machinery through subsidies and incentives, and systematic monitoring of residue burning using remote sensing tools in collaboration with the National Remote Sensing Agency (NRSA) and the Central Pollution Control Board (CPCB). Furthermore, the policy aims to facilitate financial support through a multidisciplinary and inter-ministerial approach, encouraging innovative technologies and project proposals for sustainable crop residue management.

### Conclusion

Crop residue burning represents both an environmental threat and a missed agricultural opportunity. With appropriate management strategies, crop residues can enhance soil health, support renewable energy production and strengthen rural livelihoods. Transforming residues from waste to wealth is not only essential for sustainable agriculture but also critical for India's environmental and climate resilience. A holistic approach integrating technological support, policy incentives,

market linkages and farmer education is essential to address crop residue burning effectively.

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# The hidden Danger in Cooking oil: Understanding the Adulteration of Palm Oil

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Palm oil is a fat rich source, essential commodity of great economic importance in Nigeria food system. It remains widely used in both traditional and food industry in the generations of human history. It is high in antioxidants, vitamin K, E and A which contains beneficial carotenoid. All these enhance healthy skin, vision and immune system. *Elaeis guineensis* produces high quantity of oil over small areas of land all year round with steady income which make it attractive to grower. However, the adulteration of palm oil is now a major food safety concern. This article examines the prevalence, causes and implication of palm oil adulteration. Many engagers indulge in a practice of adding harmful substances such as dye, kerosene, cheaper vegetable oil or reused oil with endless of others to palm oil. This is to increase their profit margin at the expense of the consumers, not minding the risks such as nutritional degradation, organ damage and cancerous diseases posed. This review also includes socioeconomic impact of this practice on producers and national trade reputation. Simple detection methods of the adulterated commodity were outlined, while strong calls were made to regulatory enforcement, quality control and consumer education to take proper and adequate measure to ensure the purity of palm oil. These are steps which are crucial in safeguarding public health, restoration of market trust and sustainability of the palm oil value.

## Introduction

Palm oil, fondly called “the red gold of Africa,” is one of the most consumed edible oils in Nigeria and many parts of the world. It is rich in vitamins A and E, and serves as a key ingredient in cooking, food processing, and cosmetics. However, growing concerns have emerged about the adulteration of palm oil, a practice where unscrupulous vendors mix genuine palm oil with harmful substances to improve color, volume, or profit margins.

Palm oil adulteration involves the deliberate addition of foreign substances such as artificial dyes (like Sudan III or IV), used cooking oil, or other cheaper vegetable oils. These additives may enhance the oil’s color or texture, deceiving consumers into thinking they are buying high-quality products (Okechalu et al., 2011). Common additives include Sudan dyes, recycled oil, and cheaper vegetable oils, all of which degrade quality and introduce toxic compounds (Onyeonagu et al., 2018). Studies show that adulterated palm oil can cause organ damage, oxidative stress, and even cancer (Okechalu et al., 2011). This act not only reduces nutritional value but

also poses serious health risks to consumers. Despite these dangers, local markets still sell such commodity.

Nigeria being one of the top palm oil producer established agencies such as the National Agency for Food and Drug Administration and Control (NAFDAC) and the Standards Organisation of Nigeria (SON) to regulate food quality. However, limited resources, insufficient laboratory capacity, poor coordination, and corruption hinder their effectiveness (FAO, 2020). Millions of potential export earnings are lost due to questionable quality of Nigeria palm oil (FAO, 2020). Many small-scale processors operate informally, outside official oversight, while regulatory inspections are often reactive rather than preventive. The absence of traceability systems also makes it difficult to identify the source of adulterated products once they reach consumers.

## Potential risks of palm oil Adulteration

Adulteration of palm oil has severe health consequences. Sudan dyes are carcinogenic,



potentially leading to liver and kidney damage, and long-term exposure may increase cancer risk (Onyeonagu et al., 2018). Recycled or oxidized oils contain peroxides that can cause digestive disorders, heart diseases, and cellular damage. Over time, these contaminants accumulate in body tissues, impairing normal metabolic function and weakening immunity. Beyond health, adulteration undermines consumer trust, damages export potential, and discourages genuine producers.



### Precautional Measures

Consumers can take these simple steps to determine the quality of palm oil they are about to purchase:

- Observe color: genuine palm oil is deep reddish-orange, not overly bright or fluorescent.
- Smell and texture: pure oil has a natural nutty aroma and thick texture, not watery or chemical-smelling.
- Use basic tests: when palm oil is refrigerated, adulterated samples often separate into layers.

Producers should embrace Good Manufacturing Practices (GMP), while government agencies such as NAFDAC and SON must intensify quality monitoring and public sensitization.

### Conclusion

Palm oil adulteration threatens both food safety and public health. The purity requires adherence to quality standards which should be collective effort from all the stakeholders. The “red gold” should nourish, not harm, those who consume it. Stricter enforcement against palm oil adulteration should therefore not be a mere regulatory demand, but rather a public health necessity and an economic safeguard. With all stakeholders working together as an entity, every drop of palm oil sold is ensured safe, pure and beneficial. Hence, Nigerian reputation on palm oil market can be restored to pave way for competitiveness in both regional and international trade.

### Recommendation

1. NAFDAC and SON should increase routine sampling and testing at all levels of distribution through regular market surveillance.
2. Implementation of fines and prosecution for offenders to discourage adulteration by the Legal arm of Government.
3. Equip laboratories and train inspectors in modern analytical techniques like FTIR spectroscopy, chromatography, and chemometric tools for easy detection of adulteration of oil.
4. Encourage collaboration with producer associations and research institutions for self-regulation.
5. Use media campaigns to inform the public on identifying and reporting adulterated products.



# Agricultural Hydrogels: Superabsorbent Polymers for Soil-Water Management

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Water scarcity has become a serious global challenge, affecting millions of people worldwide. It threatens food production, public health, economic stability and environmental sustainability. Communities facing water shortages often experience poverty, conflict and migration. In India, the Central Water Commission's 2024 Assessment of Water Resources shows the country's average annual water availability at about 2,115.95 billion cubic meters (BCM) with a significant portion not readily utilizable for direct use, per capita water availability was estimated at about 1,513 m<sup>3</sup> in 2024, placing India in the water-stressed category (below 1,700 m<sup>3</sup> per person). By supporting sustainable and efficient farming, hydrogels address the dual challenges of water scarcity and erratic rainfall. Their adoption can significantly improve agricultural productivity, reduce costs and ensure food security for millions of small and marginal farmers in India.

## Introduction

Water is one of the most valuable natural resources on Earth and is essential for the survival of all living organisms. It plays a fundamental role in maintaining human health, supporting agriculture, driving industrial activities and sustaining ecosystems. Industries rely on water for manufacturing, cooling, energy generation and transportation, while rivers, lakes and wetlands support biodiversity and regulate the climate. Despite its immense usefulness, water is a finite resource and its availability is increasingly under threat. Pollution from industrial waste, agricultural runoff and domestic sewage further reduces the quality of available water, rendering it unsafe for use. Water scarcity has become a serious global challenge, affecting millions of people worldwide. It threatens food production, public health, economic stability and environmental sustainability. Communities facing water shortages often experience poverty, conflict and migration. Therefore, recognizing the usefulness of water and understanding the causes and consequences of its scarcity are crucial steps toward promoting conservation, efficient use and sustainable



management of water resources for present and future generations. Climate change, overuse and poor water management worsen this challenge worldwide. Globally, freshwater suitable for human use is very limited compared to total water, only a small portion of Earth's water is freshwater and around half of the world's population experiences severe water scarcity for at least part of the year, according to the UN World Water Development Report by UN-Water/UNESCO. (Source: UNESCO). In India, the Central Water Commission's 2024 Assessment of Water Resources shows the country's average annual water availability at about 2,115.95 billion cubic meters (BCM), with a significant portion not readily utilizable for direct use, per capita water availability was estimated at about 1,513 m<sup>3</sup> in 2024, placing



India in the water-stressed category (below 1,700 m<sup>3</sup> per person). India holds only about 4 % of the world's freshwater resources while supporting a much larger share of the global population, underscoring persistent pressure on limited water supplies. Water scarcity is a growing global challenge and its impact on Indian agriculture is particularly severe. India relies heavily on freshwater for irrigation, as agriculture consumes nearly 80 % of the country's water resources. With global freshwater availability decreasing due to population growth, climate change and overexploitation, Indian farmers face reduced water supplies for crops, leading to lower yields and economic losses. Uneven rainfall, declining groundwater levels and frequent droughts further worsen the situation, especially in arid and semi-arid regions. Agricultural hydrogels are water-absorbing polymers that store and slowly release water to plants, making them an effective solution for irrigation challenges faced by Indian farmers. In water-scarce and drought-prone regions of India, these hydrogels help retain soil moisture for longer periods, reducing dependence on frequent irrigation. They enhance crop growth, improve yields and conserve water resources while preventing nutrient leaching. By supporting sustainable and efficient farming, hydrogels address the dual challenges of water scarcity and erratic rainfall. Their adoption can significantly improve agricultural productivity, reduce costs and ensure food security for millions of small and marginal farmers in India.

### Types of Agricultural Hydrogels

Agricultural hydrogels are classified based on their origin and composition.

- **Synthetic polymers** are artificially created materials, such as polyacrylamide and polyacrylate, widely used in agriculture. They act as hydrogels, absorbing and retaining large amounts of water, slowly releasing it to crops. These polymers improve soil moisture, reduce irrigation frequency, enhance crop growth and prevent nutrient leaching, making farming more efficient and sustainable.

- **Natural hydrogels** are water-absorbing materials derived from plants, algae or animal sources, such as starch, cellulose and alginate. They are biodegradable and eco-friendly, helping soils retain moisture, support plant growth and reduce water stress. Though less absorbent than synthetic types, they promote sustainable agriculture and prevent nutrient loss in crops.
- **Composite hydrogels** combine synthetic and natural polymers to balance high water retention, soil compatibility and biodegradability. They efficiently store and release water, reduce irrigation needs, prevent nutrient leaching and enhance crop growth. By integrating the strengths of both types, composite hydrogels offer a sustainable and effective solution for improving soil moisture and agricultural productivity.
- **Superabsorbent hydrogels** are polymers capable of absorbing hundreds of times their weight in water, releasing it slowly to crops, improving soil moisture, reducing irrigation, and enhancing agricultural productivity.



Fig. Types of Agricultural Hydrogels

### Working mechanism of Hydrogel Polymers

Agricultural hydrogels function as water reservoirs in soil. When incorporated into the soil, they absorb water from irrigation or rainfall, swelling to many times their weight. The water is gradually released into the surrounding soil, maintaining moisture near



plant roots over time. This reduces evaporation and runoff, ensuring that crops have a consistent water supply even during dry periods. Hydrogels also improve soil structure by increasing porosity and aeration, which enhances root growth. Some hydrogels can store and release nutrients along with water, preventing leaching. Overall, they increase water use efficiency, reduce irrigation frequency and support healthier, higher-yielding crops, especially in arid and semi-arid regions.



Fig. Working mechanism of Hydrogel Polymers

### Application of Hydrogels in Soil

Agricultural hydrogels can be applied in several ways depending on the crop, soil type, and irrigation method:

- Mixing with Soil:** Hydrogels can be mixed directly into the soil before planting, typically at a depth of 5-15 cm near the root zone. This ensures water is retained close to the plant roots for gradual absorption.
- Seed Treatment:** Seeds can be coated with hydrogel granules before sowing. This helps maintain moisture around the germinating seed, improving germination rates in dry soils.
- Root Dipping/Transplanting:** Seedlings or saplings can have their roots dipped in hydrogel slurry before transplantation. It provides immediate moisture support and reduces transplant shock.

**4. Mulch Layer or Soil Surface Application:** Hydrogels can be spread as a thin layer on the soil surface and lightly incorporated. This method helps retain surface moisture and reduces evaporation.

### Dosage and Precautions:

- Typical hydrogel application ranges from 2-10 kg per hectare, depending on soil type and crop water needs.
- Avoid placing hydrogels too deep or too far from roots, as their effectiveness depends on root proximity.
- Hydrogels should be hydrated before or during incorporation for maximum efficiency.



Fig. Application of Hydrogels in Soil

### Hydrogels Available in India

1. **Pusa Hydrogel-** IARI, New Delhi
2. **Water lock 93N-** Acuro Organics Ltd, New Delhi
3. **Agro-forestry water absorbent polymer-** Techno care Products, Ahmedabad
4. **Super absorbent polymer-** Gel Frost Packs Kalyani Enterprises, Chennai
5. **Hydrogel-** Chemtex Specialty Ltd, Mumbai
6. **Rain drops-** M5 Exotic Lifestyle Concepts, Chennai

### Effects of Hydrogel on Soil and Plants

- **Soil Moisture Retention:** Hydrogels absorb and store large quantities of water (up to 300-500 times their weight). They release water slowly, maintaining optimum soil moisture for longer periods.
- **Reduction in Water Loss:** Minimize water loss through deep percolation and evaporation. Particularly effective in sandy and light-textured soils.
- **Improvement in Soil Physical Properties:** Increase soil porosity and aggregation. Improve soil aeration and root penetration. Reduce soil compaction and crust formation.
- **Enhanced Nutrient Retention:** Reduce leaching losses of nutrients such as nitrogen, potassium, and micronutrients. Maintain nutrients in the root zone for longer durations.
- **Improved Soil Microbial Activity:** Better moisture conditions promote beneficial microbial growth. Enhance nutrient mineralization and soil biological health.

### Effect of Hydrogel on Plants

1. **Improved Seed Germination:** Provide uniform moisture around seeds. Increase germination percentage and reduce seedling mortality.
2. **Enhanced Root Growth:** Promote deeper and healthier root systems due to sustained moisture availability. Improve root length and biomass.
3. **Increased Plant Growth and Biomass:** Better water and nutrient availability lead to improved vegetative growth. Increase leaf area, plant height, and dry matter accumulation.
4. **Drought Stress Alleviation:** Act as a moisture buffer during dry spells. Improve plant tolerance to water stress conditions.
5. **Improved Nutrient Use Efficiency:** Enhance uptake efficiency of applied fertilizers. Reduce fertilizer requirement in some crops.

### Limitations

- Effectiveness decreases in heavy clay soils.
- Excess application may reduce soil aeration.
- Synthetic hydrogels may degrade slowly and are cost-intensive.
- Performance depends on soil type, crop, climate, and management practices.

### Is Hydrogels Harmful to Nature?

Hydrogels used in agriculture are primarily superabsorbent polymers (SAPs), commonly based on polyacrylate or polyacrylamide, designed to improve soil water retention. From an environmental perspective, their impact depends on chemical composition, application rate and degradation behavior. Most commercial agricultural hydrogels are considered low-toxicity and are applied at very small doses ( $\text{kg ha}^{-1}$ ), minimizing direct ecological risk. Studies indicate that properly formulated hydrogels do not significantly affect soil pH, salinity or microbial activity and can indirectly benefit soil ecosystems by maintaining favorable moisture conditions. However, synthetic hydrogels are not fully biodegradable and may persist in soil for several years, raising concerns about long-term accumulation and potential microplastic formation upon degradation. Excessive or improper application may reduce soil aeration and alter soil structure, particularly in fine-textured soils. Additionally, poorly manufactured polymers may contain trace residual monomers (e.g., acrylamide), which are potentially toxic, though regulated products remain within safe limits. In contrast, bio-based and biodegradable hydrogels derived from natural polymers (e.g., cellulose, starch, chitosan) present lower environmental risks and align better with sustainable agriculture goals, though they often have lower durability. In conclusion, hydrogels are not inherently harmful to nature when used judiciously and sourced from certified manufacturers. Environmental risks are mainly associated with long-term persistence and misuse, highlighting the need



for regulated application and continued development of eco-friendly alternatives.



Fig. Agricultural Hydrogels as Water Reservoirs in Soil

**Future of Hydrogels**

The future of hydrogels in agriculture lies in biodegradable, eco-friendly and smart polymers with improved efficiency and safety. Advances will focus on bio-based hydrogels, nano-hydrogels and stimuli-responsive materials that release water and nutrients based on soil moisture and root demand. Integration with precision agriculture, drip irrigation and climate-smart farming will enhance water productivity, reduce input costs and support sustainable crop production under increasing water scarcity and climate change pressures.

**Conclusion**

Hydrogels in agriculture enhance soil water retention, improve nutrient use efficiency, support plant growth and mitigate drought stress. When applied judiciously, they reduce irrigation demand and stabilize yields. Environmentally safe formulations and controlled use make hydrogels a

promising tool for sustainable and climate-resilient agriculture.

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# Seaweed Farming and Its Importance

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Seaweed farming is a sustainable and climate-resilient aquaculture practice that plays an important role in environmental protection, food security, and livelihood generation. It requires no arable land, freshwater or chemical fertilizers, making it an environmentally friendly alternative to terrestrial agriculture. Seaweeds absorb excess nutrients and carbon dioxide from seawater, helping to reduce eutrophication and mitigate climate change while improving coastal ecosystem health. Globally, seaweed farming is one of the fastest-growing sectors of aquaculture with Asia leading production and India emerging as a promising contributor, particularly along the Tamil Nadu and Gujarat coasts. Seaweeds are rich in vitamins, minerals, dietary fiber and bioactive compounds and are widely used in food, pharmaceutical, cosmetic, fertilizer and biofuel industries. In addition to their nutritional and industrial value, seaweed farming provides income and employment opportunities for coastal communities, especially women. Despite challenges such as environmental variability and market constraints, technological advancements and policy support can enhance productivity and sustainability.

## Introduction

Seaweed farming is a climate-resilient aquaculture practice. This cultivation does not need land, freshwater and fertilizers, For coastal populations, it offers a varied and sustainable means of subsistence. It reduces the effects of oceanic eutrophication and acidification and oxygenates the seawater for a healthy ecosystem. Seaweed, for example, has traditionally been farmed and processed for food in several Asian nations (including China, Japan and South Korea) Hamed *et al.*, 2015, FAO 2016. Seaweed cultivation is one such viable alternative, a promising marine-based production approach that can pave the way for a long-term climate-resilient solution. Furthermore, seaweed farming has sparked international attention due to the numerous applications of this increasing resource in food, biofuels, pharmaceuticals, fertilizers, and animal feed, making it an important environmental and

economic resource. Important seaweed farming techniques have been created to increase output while including environmentally and economically sound strategies. These include conventional nearshore rope farming and sophisticated offshore cultivation employing integrated multi-trophic aquaculture (IMTA) systems. Seaweed farming, also known as seaweed aquaculture, has emerged as one of the fastest-growing sectors of aquaculture. More than 95% of the world's seaweed supply comes from farming rather than wild harvesting, highlighting its growing economic and environmental significance (Buschmann *et al.*, 2017).

## Seaweeds

There are currently about 7000 species of red algae, 2000 species of brown algae, 1800 species of green algae, and 1500 species of blue-green algae. From the intertidal zone to the deep ocean, seaweeds are



simply marine macroalgae. Seaweeds, sometimes referred to as marine macroalgae, are one of the most significant and profitable marine source commodities. They are fast-growing marine plants, requiring no fresh water, fertilizers, or arable land to flourish. Seaweed contains high levels of vitamins, minerals, and amino acids. It is beneficial in combating illnesses such as cancer, diabetes, arthritis, heart conditions, and elevated blood pressure. Furthermore, it enhances the immune system and supports overall bodily wellness. Seaweeds play a vital role in marine ecosystems by contributing to primary production, nutrient cycling, and habitat formation. Commercially, seaweeds are valued for their cell wall polysaccharides, such as agar, algin, carrageenan as well as for their bioactive metabolites, manure and fodder. They are used commercially in the mining, culinary, pharmaceutical, and cosmetics sectors. Some seaweeds are also gaining importance as healthy food for human consumption. Seaweeds have been cultivated for decades in 61 nations and territories, accounting for more than half of global marine and coastal aquaculture production (FAO 2022).

### Seaweed Production Status – Global and India

According to FAO's State of World Fisheries and Aquaculture 2024, global production of algae—predominantly seaweed—reached 37.8 million tonnes in 2022, highlighting the rapid growth and increasing importance of seaweed aquaculture worldwide.

### Types of seaweed

Seaweeds are classified into three major taxonomic groups based on their pigmentation:

1. Red algae (Rhodophyta)
2. Brown algae (Ochrophyta, Phaeophyceae)
3. Green algae (Chlorophyta)

### Commercially Important Seaweed Species

The main commercially farmed species can be summarised into five main seaweed species groups. They are *Laminaria* or Kelp, *Pyropia* or *Porphyra* sp,

*Gracilaria*, *Kappaphycus* or *Euchomoids* and *Undaria*.

### Farming Method

Seaweed farming involves the cultivation of seaweed species in marine or brackish water environments using simple and cost-effective techniques. Raft farming, net culture, long-line systems, and rope culture are common farming techniques. These methods allow seaweed to grow naturally by absorbing sunlight, carbon dioxide, and nutrients from seawater (FAO, 2022). Asia dominates global seaweed production, with China and Indonesia being the largest producers, followed by countries such as the Philippines, South Korea, and Japan. In India, seaweed farming is expanding along the coasts of Tamil Nadu, Gujarat, and the Lakshadweep Islands, where it provides an alternative livelihood for fishing communities (CMFRI, 2019). One of the major advantages of seaweed farming is its sustainability. Unlike terrestrial agriculture, it does not require freshwater, fertilizers, or arable land, making it an environmentally friendly food production system (Duarte *et al.*, 2017).

### Long-Line Rope Method

This is a modified conventional off-bottom farming approach that shares few parallels with the raft method. Seedlings weighing around 100-150 g are tied to a rope with raffia or abraider between anchors. The main rope is 6-8 mm in diameter and approximately 20 m in length. Longline ropes are maintained afloat in water by tying floats at regular intervals and anchoring them on both ends. Anchoring timbers include casuarina, eucalyptus, and bamboo. Poles are erected at 3 m intervals in a square pattern, with 12 mm polypropylene rope knotted in any two parallel directions (depending on tide and current directions). After that, the 3 mm seeded ropes are tied at 10-cm intervals. Care must be taken to ensure that the seaweed is always buried (0.5 m below the surface) and receives adequate sunshine. Seeding is typically done in the water to prevent seedling loss, which can occur if ropes are seeded on the land and dragged into the sea. This



farming approach is ideal for locales with moderate wave activity, particularly those with a low grazer density. It is extensively accepted in the South Ramanathapuram, Pudukkottai, and Tuticorin regions of Tamil Nadu.

### Net Bag Method

The net bag approach was mostly used for *Gracilaria dura*. The cultivation method was modified from the method (Veeragurunathan et al., 2016) stated in the previous section. This method involves seeding a 75-cm-long bag made from commercial fish net with 200-300-g seedlings (Fig. 1B). (Veeragurunathan et al., 2016) To prevent grazing, the net bag is completely coated in agro net (1.0-0.2-mm mesh size and 90- $\mu$ m thickness). The bag is then linked to an 8-mm polypropylene rope, which is tied on both sides to vertical bamboo poles. On average, a biomass of 900 g fresh weight can be obtained from each of the seedlings in 45 days.

### Floating Bamboo Raft Method

A bamboo raft (8-10 cm in diameter and 3 m in length) serves as the main culture frame (Fig. 1C). The cultivation method was adapted from the old standard approach, with certain changes. To keep the angular pieces intact, they are diagonally attached using supporting bamboo. To secure and maintain buoyancy, the raft clusters are connected together using an anchor. Bottom netting is provided to prevent debris drift and limit grazing. The seeding is done on shore, and the seeded rafts are then transported into the open sea. Harvesting is typically completed after 45 days. This method is suited for modest water movement. It has been popularly embraced in the Tamil Nadu coastal areas. (Eswaran et al., 2002)

### Bottom-Culture Method

A square net (2 m x 2 m) composed of polypropylene rope (3-mm diameter) is seeded with an initial seedling weight of 1.5 kg fresh wt. net. The seeded nets are linked at all four corners to vertical bamboo poles set up in the sea at 1.5 depths. Stone sinkers are used to secure the seeded nets 25 cm above the

bottom. After 45 days of growth, the biomass can reach 7kg fresh weight net.

## Importance of Seaweed and Its Farming

### Environmental Importance

The sustainability of the environment is greatly aided by seaweeds. During photosynthesis, they take in a lot of carbon dioxide, which helps slow down climate change. Additionally, seaweed farms reduce eutrophication and enhance water quality by removing excess nutrients like phosphorus and nitrogen from coastal waterways (Duarte et al., 2017). Seaweed farms also maintain biodiversity and improve the health of coastal ecosystems by giving fish and other marine species a place to live and spawn.

### Economic and Social Importance

Seaweed farming supports the livelihoods of millions of people worldwide, particularly in developing coastal regions. It promotes gender equity and rural development by requiring little capital investment and offering consistent income opportunities, particularly for women (Valderrama et al., 2015). Food processing, pharmaceuticals, cosmetics, and bioproducts are just a few of the industries that the global seaweed industry serves. Seaweed-derived hydrocolloids including agar, alginate, and carrageenan are frequently utilized as thickeners and stabilizers in industrial and food products (Bixler and Porse, 2011)

### Nutritional and Industrial Importances

Essential nutrients such as vitamins A, B, C, and E, minerals (calcium, iron, and iodine), dietary fiber, and bioactive substances are abundant in seaweeds. Seaweeds are being marketed more and more as functional foods and dietary supplements because of their high nutritional content (Holdt and Kraan, 2011). Seaweeds are utilized in industry to make biodegradable products, fertilizers, medications, animal feed, and cosmetics. Additionally, recent studies demonstrate their potential application in the manufacturing of bioplastics and biofuel, supporting a circular and bio-based economy.



## Challenges in Seaweed Farming

Seaweed cultivation has a number of difficulties despite its advantages. Poor farm management, environmental changes, and disease outbreaks can all lower productivity. Other obstacles include insufficient processing facilities, price volatility, and market access, especially for small-scale producers (Buschmann *et al.*, 2017). Furthermore, to prevent detrimental ecological effects like habitat modification and genetic contamination of wild populations, large-scale seaweed farming needs to be carefully managed.

## Future Prospects

Seaweed farming has a bright future due to the growing need for sustainable food and biobased products worldwide. Productivity and resilience are anticipated to increase due to developments in biotechnology, selective breeding, and farming technology. Seaweed farming is becoming more important in the blue economy as it is being investigated as a method for carbon sequestration and climate adaption. (Duarte *et al.*, 2017).

## Conclusion

Seaweed and its farming provide a sustainable and environmentally friendly answer to global issues such as food security, climate change, and livelihood generation. With proper management, regulatory backing, and technical innovation, seaweed farming has the potential to play a critical role in long-term coastal development and economic prosperity.

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## Climate Change and Groundwater Sustainability in India's Semi-Arid Regions

### *Recharge, rainfall variability, and long-term groundwater security*

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Groundwater is the lifeline of India's semi-arid regions, including Rajasthan, Gujarat, Maharashtra, Telangana, Karnataka, and central India, sustaining agriculture, rural livelihoods, and domestic water supply. Millions of farmers and households depend on it as the primary source of water for irrigation, drinking, and livestock. However, groundwater availability is increasingly threatened by climate change, erratic rainfall, rising temperatures, and extreme weather events. At the same time, human activities such as unregulated extraction, borewell proliferation, and cultivation of water-intensive crops have placed immense stress on aquifers. Understanding the challenges of rainfall variability, groundwater recharge, and sustainable management strategies is essential to ensure long-term water security in these regions.

#### Monsoon Patterns and Rainfall Variability

The southwest monsoon, which delivers most of the annual rainfall in just three to four months, is critical for groundwater replenishment in semi-arid India. Historically, communities and ecosystems adapted to seasonal rainfall patterns, but climate change has begun to disrupt this rhythm. Observed changes include delayed monsoon onset, prolonged dry spells, and short-duration, high-intensity rainfall events. These trends reduce effective groundwater recharge because heavy rains often result in surface runoff rather than infiltration, and rising temperatures increase evaporation, reducing soil moisture. Even when annual rainfall totals remain near historical averages, uneven distribution diminishes groundwater replenishment. This effect is particularly severe in hard rock terrains, which have limited natural storage.

#### Human Impact on Groundwater

While climate variability affects recharge, human activity has greatly intensified groundwater stress. Borewells, subsidized electricity for pumping, and cultivation of crops such as sugarcane, paddy, and cotton have driven extraction beyond natural recharge capacity. In several districts of Rajasthan and Gujarat, water tables have declined by 2–4

meters over the past decade. Wells that once provided free-flowing water now require deeper drilling, and urbanization has reduced natural infiltration by encroaching on ponds, wetlands, and traditional recharge zones. Hard rock aquifers, which recharge slowly, are particularly vulnerable. Prolonged dry years coupled with over-extraction threaten both agricultural productivity and rural livelihoods, making effective management urgent.

#### The Role of Recharge in Groundwater Sustainability

Recharge—the process by which rainfall percolates into aquifers—is the foundation of sustainable groundwater management. In semi-arid regions, only a small portion of rainfall contributes to recharge, so protecting and enhancing recharge zones is crucial. Traditional water bodies, including village tanks, ponds, and lakes, historically replenished aquifers but have often fallen into disrepair. Managed Aquifer Recharge (MAR) techniques, including check dams, percolation tanks, farm ponds, contour trenches, and recharge wells, help capture runoff and promote infiltration. In addition, green infrastructure such as vegetative barriers, soil bunds, and afforestation in catchment areas can improve percolation and reduce soil erosion. Micro-recharge interventions in farms, such as field bunding and shallow recharge pits,



provide localized benefits and can collectively enhance aquifer replenishment across large areas.

### **Demand-Side Management: Efficient Water Use**

While enhancing recharge is critical, reducing water demand is equally important. Efficient irrigation systems, such as drip and sprinkler methods, reduce water consumption by 30–50% compared to traditional flood irrigation. Crop diversification toward drought-tolerant crops such as millets, pulses, and oilseeds reduces dependence on groundwater. Practices such as mulching, soil moisture conservation, and rainwater harvesting on-farm can further reduce water requirements. Proper irrigation scheduling based on soil moisture levels prevents overuse and allows aquifers to recover naturally. Community engagement, including farmer cooperatives and village water committees, ensures monitoring of groundwater extraction and adherence to sustainable practices. Integrating supply-side and demand-side measures ensures groundwater remains viable even during periods of erratic rainfall.

### **Climate Adaptation Strategies for Agriculture**

Climate adaptation strategies are vital to reduce pressure on groundwater in semi-arid regions. These include crop rotation, selection of drought-resistant crop varieties, and flexible planting schedules that align with rainfall patterns. Agroforestry and mixed cropping systems can improve soil moisture retention and reduce evaporation losses. Farmers are increasingly adopting water-smart practices such as alternate wetting and drying (AWD) in rice cultivation, which reduces irrigation requirements while maintaining yields. Integrating traditional knowledge, such as using indigenous water-conserving crops and rotational grazing, with modern techniques enhances both resilience and sustainability.

### **Technology and Data-Driven Groundwater Management**

Modern technology plays a key role in sustainable groundwater management. Remote sensing and GIS mapping can identify stressed aquifers and potential

recharge zones, while satellite-based monitoring, including GRACE satellites, tracks long-term changes in groundwater storage. Hydrological modeling and forecasting enable predictions of aquifer responses to rainfall variability, extraction, and climate change scenarios. Early warning systems alert authorities and farmers to potential droughts or declining water tables. Data-driven approaches allow evidence-based planning, targeted interventions, and efficient allocation of resources. Mobile applications and community-level water monitoring tools are also helping local users track well levels and water quality, enabling proactive management.

### **Policy, Governance, and Community Participation**

Effective groundwater sustainability requires robust policy and governance frameworks alongside community engagement. Policies should regulate extraction through licensing and monitoring, protect recharge zones from encroachment, incentivize water-efficient cropping patterns, and integrate climate projections into water planning. Governments can provide subsidies for water-efficient technologies, promote watershed development programs, and encourage community-led groundwater management. Local participation is critical, with village water committees and farmer cooperatives monitoring usage, maintaining recharge structures, and promoting sustainable practices. Awareness campaigns, capacity-building programs, and participatory water budgeting can reinforce responsible water use and ensure equitable distribution.

### **Long-Term Groundwater Security and Climate Resilience**

Groundwater underpins agriculture, food security, and rural livelihoods. Climate change, erratic rainfall, and overextraction threaten the delicate balance between recharge and demand in semi-arid regions. Securing long-term groundwater availability requires integrated strategies, including protecting and enhancing recharge through natural and artificial measures, reducing water demand via efficient



irrigation and crop diversification, leveraging technology for monitoring and forecasting, and strengthening governance and community participation. By implementing these measures, semi-arid India can build resilient groundwater systems capable of sustaining agriculture and communities under uncertain climatic conditions.

### Conclusion

Groundwater sustainability in India's semi-arid regions is at a critical juncture. Erratic rainfall, rising temperatures, and unsustainable extraction patterns pose serious threats to aquifers, agriculture, and rural

livelihoods. Understanding recharge mechanisms, promoting water-efficient practices, applying technology, and enforcing effective governance are essential to secure this vital resource. Immediate and coordinated action is necessary to prevent a silent crisis and ensure that groundwater continues to sustain millions of people and ecosystems. Protecting groundwater today will secure food security, climate resilience, and livelihoods for future generations.

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# Artificial Recharge of Groundwater: Modern Techniques and Field-Level Innovations

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## Introduction: Growing Stress on Groundwater Resources

Groundwater plays a decisive role in Maharashtra's water security, forming the primary source of irrigation, drinking water, and industrial supply across rural and urban areas. Over the years, rapid agricultural expansion, population growth, and increasing reliance on borewells have resulted in unsustainable groundwater extraction. Climate change has further intensified this stress by altering rainfall patterns, increasing temperatures, and extending dry periods. The declining reliability of surface water sources has pushed communities deeper into aquifers, often beyond safe recharge limits. In response to this growing crisis, artificial recharge of groundwater has emerged as a scientifically sound and environmentally sustainable solution to restore aquifer balance and ensure long-term water availability.

## Need and Importance of Artificial Recharge of Groundwater

Artificial recharge refers to the intentional enhancement of groundwater storage by facilitating the downward movement of surface water into aquifers. Although Maharashtra receives substantial monsoon rainfall, a large proportion of this water is lost as rapid runoff due to hard rock geology, degraded catchments, and short-duration intense rainfall events. Climate change has amplified this imbalance by reducing infiltration opportunities and increasing evaporation losses. Artificial recharge helps capture surplus monsoon water, store it underground with minimal loss, and make it available during dry seasons. This process not only strengthens groundwater reserves but also reduces dependence

on large surface reservoirs and improves climate resilience.

## Recharge Shafts: Direct Replenishment of Deep Aquifers

Recharge shafts are engineered vertical structures designed to transmit surface water directly into deeper aquifer zones by bypassing low-permeability soil and rock layers. In Maharashtra, where basaltic formations dominate, natural percolation is often limited due to compact rock layers. Recharge shafts overcome this constraint by connecting surface runoff to fractured and weathered zones within aquifers. These structures typically include filtration chambers to remove silt and debris, ensuring that only clean water enters the subsurface system. Recharge shafts are especially valuable in drought-prone areas and locations with failed or low-yield borewells, as they help restore aquifer pressure and improve long-term well sustainability.

## Percolation Tanks: Enhancing Shallow and Intermediate Groundwater Storage

Percolation tanks are large, shallow reservoirs constructed across natural drainage lines to temporarily store monsoon runoff and allow gradual infiltration into surrounding soil and rock formations. Unlike conventional reservoirs, their primary purpose is groundwater recharge rather than surface water storage. The extended residence time of water in percolation tanks facilitates sustained recharge of shallow and intermediate aquifers. In agricultural regions, this leads to improved groundwater availability in open wells and shallow borewells, better soil moisture conditions, and increased crop reliability. The effectiveness of percolation tanks



depends heavily on proper site selection, catchment treatment, and regular maintenance to prevent siltation.

### **Check Dams and Nala Bunds: Distributed and Decentralized Recharge Structures**

Check dams and nala bunds are small barriers constructed across seasonal streams to slow the velocity of flowing water and promote infiltration. These structures play a vital role in decentralized groundwater recharge by spreading water over a larger area and increasing the contact time between water and soil. In semi-arid landscapes, check dams help reduce soil erosion, stabilize streambeds, and support groundwater–surface water interaction. Their cumulative impact across a watershed can significantly enhance groundwater storage, making them an effective and economical solution for rural water management.

### **Injection Wells: Managing Recharge in Urban and Peri-Urban Areas**

Urbanization has drastically reduced natural recharge opportunities by replacing permeable surfaces with roads, buildings, and drainage networks. Injection wells provide an effective method for artificial recharge in such settings by directing treated rainwater or stormwater directly into deep aquifers. These wells are designed with filtration and monitoring systems to prevent contamination and protect groundwater quality. Injection wells not only help replenish aquifers but also assist in managing urban flooding and reducing pressure on centralized water supply systems. When integrated into urban planning, they contribute to sustainable and resilient city water management.

### **Hydrological Impacts of Artificial Recharge**

Artificial recharge positively alters the groundwater regime by reducing seasonal water-level fluctuations and increasing base flow availability. Stabilized groundwater levels enhance aquifer storage capacity and improve the reliability of wells throughout the year. Recharge also helps mitigate the effects of prolonged dry spells by providing a subsurface buffer

against drought conditions. From a hydrological perspective, artificial recharge strengthens the connection between rainfall events and long-term groundwater availability, transforming episodic rainfall into a dependable water resource.

### **Agricultural and Socio-Economic Benefits**

The agricultural sector is one of the largest beneficiaries of artificial groundwater recharge. Improved groundwater availability reduces irrigation risk, lowers pumping costs, and supports sustained crop production. Stable water supplies encourage farmers to adopt diversified cropping systems and invest in improved agricultural practices. Over time, enhanced groundwater security contributes to increased farm incomes, reduced vulnerability to drought, and improved rural livelihoods. By ensuring dependable water access, artificial recharge also reduces seasonal migration and strengthens rural economies.

### **Role of Community Participation and Governance**

Engineering structures alone cannot ensure groundwater sustainability. Community participation and effective governance are essential to protect recharge gains. When local users are involved in planning, implementation, and maintenance, recharge systems are more likely to function effectively over the long term. Practices such as water budgeting, regulation of borewell drilling, and alignment of cropping patterns with water availability help prevent over-extraction. Treating groundwater as a shared resource rather than an individual asset is critical for equitable and sustainable management.

### **Technical and Institutional Challenges**

Despite its advantages, artificial recharge faces several challenges. Poor design or inadequate maintenance can reduce recharge efficiency due to siltation or structural damage. In some cases, lack of detailed hydrogeological assessment results in poorly performing structures. Unregulated groundwater extraction remains the most significant threat, as



excessive pumping can quickly negate the benefits of recharge. Climate variability adds further uncertainty, making it necessary to adopt adaptive planning and continuous monitoring.

**Future Directions for Sustainable Groundwater Management**

The future of artificial recharge lies in its integration with watershed development, efficient irrigation technologies, groundwater regulation, and climate-adaptive planning. Advances in remote sensing, GIS-based aquifer mapping, and real-time monitoring systems offer new opportunities to improve recharge planning and performance evaluation. A coordinated approach involving engineers, policymakers, researchers, and local communities is essential to ensure that artificial recharge contributes meaningfully to long-term water security.

**Conclusion: Rebuilding Water Security from Beneath the Ground**

Groundwater may remain invisible, but it is central to Maharashtra’s environmental and economic stability. Artificial recharge represents a powerful approach to restoring balance between groundwater withdrawal and replenishment. By combining scientific design, strong governance, and community participation, Maharashtra can transform groundwater from a declining resource into a resilient foundation for sustainable development. Protecting groundwater today is an investment in food security, rural livelihoods, and the state’s climate-resilient future.

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## Integrated approaches for managing Fall Armyworm (*Spodoptera frugiperda*) in maize

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### Introduction

In India, maize is the third most important crop after rice and wheat, providing food and fodder and serving as a source of basic raw materials for several industrial products such as starch, oil, protein, beverages, food, and alcohol. Thus, maize has gained a significant position as an industrial crop, with 83% of its produce being utilized in the starch and feed industries. Maize cultivation in India covers an area of 8.69 million hectares, with a production and productivity of 21.81 million tonnes and 2509 kg/hectare, respectively. Andhra Pradesh, Karnataka, Bihar, Maharashtra, Rajasthan, Madhya Pradesh, and Uttar Pradesh are the major maize-producing states in India.

The fall armyworm (FAW), *Spodoptera frugiperda*, an invasive pest, has become a threat to farmers and Indian agriculture and was first detected in the Indian subcontinent in May 2018 in maize fields at an agricultural college. Early emergence in the crop life cycle, voracious feeding habits, highly invasive behavior, high fecundity, rapid migration, and the irreparable nature of crop damage make FAW a major pest of maize (CABI, 2019). Its arrival in India is difficult to trace. However, it is believed that FAW arrived in India from Africa through human-assisted transport, natural migration (capable of flying hundreds of kilometers in a single night on prevailing winds), and evaded regulatory systems or quarantine. Increased cloud cover, coupled with lower temperatures and higher rainfall, leads to rapid population growth and outbreaks of FAW.

### Potential for Damage

Fall Armyworm (FAW) has caused widespread damage to crops, especially maize, which is crucial for the animal feed industry, and crops such as sugarcane and millet. Consequently, India is

forced to import maize for the feed and starch industries, which together consume approximately 80 percent of the total domestic production. Due to FAW infestation and adverse weather conditions, maize production declined by about 15-20 percent during 2018. As a result, prices have increased sharply, making the rapidly growing feed industry uneconomical. This pest can cause significant crop damage and ultimately harm farmers' profitability. Ultimately, increased raw material costs will lead to higher prices for meat, eggs, and milk, negatively impacting consumers.

### FAW Life Cycle

The FAW life cycle is completed in about 30 days during the summer, but takes 60 days in spring and autumn, and 80 to 90 days during the winter.

**Egg:** The number of eggs per mass varies considerably but is often 100 to 200, and total egg production per female averages about 1500 with a maximum of over 2000. The female also deposits a layer of grayish scales between the eggs and over the egg mass, imparting a furry or moldy appearance. Duration of the egg stage is only two to three days during the summer months.

**Larva:** There are six instars in fall armyworm. Young larvae are greenish with a black head, the head turning orangish in the second instar. In the third instar, the dorsal surface of the body becomes brownish, and lateral white lines begin to form. In the fourth to the sixth instars the head is reddish brown, mottled with white, and the brownish body bears white sub-dorsal and lateral lines. Elevated spots occur dorsally on the body; they are usually dark in colour, and bear spines. The presence of four black spots arranged in square shape on dorsal aspect of the penultimate abdominal segment is another important mark to differentiate it from other cutworms. The



face of the mature larva is also marked with a white inverted "Y". Duration of the larval stage tends to be about 14 days during the summer and 30 days during cool weather.



*Life cycle of Fall army worm (Egg, Larva, Pupa, Adult)*

**Pupa :** Pupation normally takes place in the soil, at a depth 2 to 8 cm. The larva constructs a loose cocoon, oval in shape by tying together particles of soil with silk. If the soil is too hard, larvae may web together leaf debris and other material to form a cocoon on the soil surface. The pupa is reddish brown in color. Duration of the pupal stage is about eight to nine days during the summer, but reaches 20 to 30 days during the winter (Devi et al.,2024).

**Adult:** Adults are nocturnal, and are most active during warm, humid evenings. After a preoviposition period of three to four days, the female normally deposits most of her eggs during the first four to five days of life, but some oviposition occurs for up to three weeks. Duration of adult life is estimated to average about 10 days, with a range of about seven to 21 day.

### Nature and Symptoms of Damage

Young larvae initially feed on the leaf tissues from one side, leaving the opposite epidermal layer intact. By the second or third instar, the larvae begin to bore holes in the leaves and feed inward from the leaf margins. Feeding on corn often results in a characteristic row of holes (shot holes) in the leaves. Older larvae cause extensive defoliation, often

leaving only the stalks and/or tattered remnants of the corn plants. The early whorl stage is least susceptible to damage, the mid-whorl stage is intermediate, and the late whorl stage is most susceptible to injury.



Symptoms of damage

### Economic threshold

On maize, if 5% of seedlings are cut or 20% of whorls of small plants (during the first 30 days) are infested, it is recommended that an insecticide be applied. In sorghum, the pest threshold level is as one (or two) larvae per leaf whorl and two per head

### FAW management

- i) **Monitoring :** Install pheromone traps at a rate of 5/acre in the current and potential spread areas during the cropping season and off-season.
- ii) **Scouting:** Start monitoring maize plants as soon as they emerge and reach the early whorl stage (3-4 weeks after emergence) – action can be taken if 5% of the plants are damaged ( FAO, 2017).
- iii) **Cultural control:**
  - Summer ploughing in deep to expose pupae of FAW to predatory birds, heat *etc.*



- Clean and weed free cultivation to destroy the alternate hosts and balanced use of fertilizers.
- Dig trench around the field and fill with water and insecticide to avoid migration of FAW larvae from one to another field (Kansiime et al., 2019).
- Cultivation of maize hybrids with tight husk cover will reduce ear damage by FAW

#### iv) Mechanical control :

- Hand picking and destruction of egg masses and neonate larvae in mass by crushing or immersing in kerosine water
- Application of dry sand in to the whorl of affected maize plants soon after observation of FAW incidence in the field
- Application of Sand + lime in 9:1 ration in whorls in first thirty days of sowing
- Mass trapping of male moths using FAW specific pheromone traps @ 15/acre

#### v) Biological control:

- Bio-pesticides: If infestation level is at 5% damage in seedling to early whorl stage and 10% ear damage, then use following entomopathogenic fungi and bacteria: *Metarhizium anisopliae*, *Nomuraea rileyi*, *Beauveria bassiana*, *Verticillium lecani* (1 × 10<sup>8</sup>cfu/g) @ 5g/litre whorl application. Repeat after 10 days if required *Bacillus thuringiensis* var. *kurstaki* formulations @ 2g/l (or) 400g/acre
- Apply Azadirachtin 1% EC @ 10,000 ppm or neem oil @ 5 mL/lit. as oviposition deterrent on one week after sowing.

#### vi) Chemical control:

- Seed treatment: Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6 ml/kg seed will be effective for 15-20 days.

- First window (seedling to early whorl stage): To control FAW larvae at 5% damage to reduce fresh egg-laying capacity, spray 5% NSKE/Azadirachtin 1500ppm @ 5ml/l water.
- Second window (mid-whorl to late whorl stage): To manage second and third instar larvae with more than 10% foliar damage, the following chemicals can be used until the early tasseling stage:
  - Spinetoram 11.7% SC or Chlorantraniliprole 18.5% SC or Thiamethoxam 12.6% + Lambda Cyhalothrin 9.5% ZC should be used.
- Third window (emergence to tasseling and 8 weeks after tasseling): Insecticide management is not cost-effective at this stage. Use biopesticides at this stage. Handpicking of larvae is advised.
- All sprays should be directed towards the whorl during the early hours of the day or in the evening.

**Conclusion:** The fall armyworm first appeared on maize in Karnataka in 2018 and quickly spread to other southern states, except Telangana. Identifying an invasive pest in India can be challenging due to a lack of reference materials and type specimens. The pest's rapid spread in India can be attributed to its voraciousness, rapid flight, and more than 80 alternate hosts. In India, the development of IPM for pest management is still in its early stages due to a lack of basic information. FAW infestations were reported during kharif 2019 in Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra, Rajasthan, Madhya Pradesh, Uttar Pradesh, and Bihar. FAW has been effectively managed in North Eastern states such as Mizoram, Manipur, Nagaland, Assam, Arunachal Pradesh, Tripura, Sikkim, and Meghalaya through early crop scouting and monitoring efforts. To achieve freedom from FAW in other parts of the country, regular awareness training for maize growers and capacity building for early scouting, surveillance, and monitoring of FAW incidence



among extension officers and input dealers are crucial.

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# Changing Pest–Natural Enemy Synchrony Under Climate Stress: A Critical Challenge for Indian Agriculture

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## Introduction

Climate change is profoundly altering agroecosystems worldwide, not only by directly affecting crop growth but also by disrupting the delicate balance between insect pests and their natural enemies (predators and parasitoids). This balance — known as *pest–natural enemy synchrony* — is essential for effective biological control and sustainable pest management. As global temperatures rise and weather patterns become more erratic, the timing and interaction between pest populations and their natural enemies are increasingly desynchronized, leading to uncontrolled pest outbreaks and increased crop losses in India and beyond.

## Understanding Pest–Natural Enemy Synchrony

In natural agroecosystems, many pest species and their associated natural enemies evolve synchronized life cycles and behaviors. For example, predators may peak in abundance when their prey (pests) reach high numbers, thus limiting pest damage naturally. This synchrony is governed by environmental cues such as temperature, humidity, and photoperiod. However, climate change — especially rising temperatures and variable precipitation — is altering these cues, leading to temporal mismatches that weaken biological control.

## How Climate Stress Disrupts Synchrony

### 1. Temperature-Driven Phenological Shifts

Insects are poikilotherms; their biology is regulated by environmental temperature. Higher temperatures can accelerate pest development and reproduction, allowing them to complete more generations within a season. This rapid pest proliferation may outpace the development of their natural enemies, resulting in

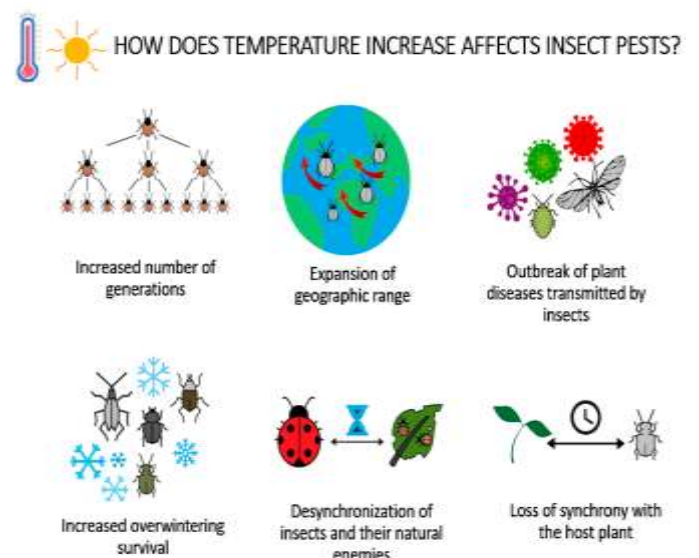
weakened predator or parasitoid responses at critical times.

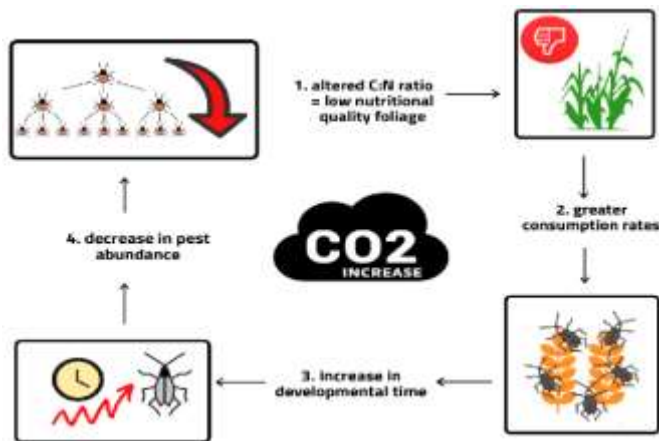
Similarly, increased CO<sub>2</sub> levels and altered rainfall also contribute to changes in pest and natural enemy biology, indirectly affecting their interactions and temporal overlap.

## Implications for Biological Control

Desynchronization can significantly **reduce the effectiveness of biological control**, a key pillar of Integrated Pest Management (IPM). Natural enemies may emerge too late or in insufficient numbers to suppress peak pest populations, resulting in greater reliance on chemical insecticides, which further disrupt beneficial insect populations.

For instance, in maize ecosystems, fall armyworm (*Spodoptera frugiperda*) and its parasitoids have shown climate-linked variations in timing and abundance, raising concerns for future control efficiency.





(Sendra et. al., 2021)

### Evidence from Indian Agroecosystems

Although specific Indian studies directly on climate-induced asynchrony are still emerging, research on **seasonal dynamics of pests and natural enemies** highlights the influence of weather parameters on both groups. For example, studies on linseed and soybean ecosystems in India correlate pest and natural enemy abundance with temperature and humidity variations, underscoring the sensitivity of insect interactions to climate factors.

Such findings indicate that climatic variability can shift peak pest and predator periods, a trend expected to intensify under future climate scenarios.

### Consequences for Indian Agriculture

The breakdown in synchrony has several serious consequences:

- **Increased pest outbreaks:** Without timely natural enemy regulation, pest populations can explode.
- **Higher crop losses:** Disrupted control increases the risk of economic damage and reduces food security prospects.
- **Greater pesticide use:** Farmers may resort to insecticides, which can further harm natural enemy populations and environmental health.

### Adaptive Management Strategies

To mitigate these challenges, Indian researchers and policymakers need to focus on:

1. **Enhanced Monitoring:** Establish long-term pest and natural enemy monitoring networks to detect phenological changes early.
2. **Phenology-based Forecast Models:** Develop predictive tools that integrate climate data to forecast pest peaks and optimal natural enemy activity.
3. **Conservation Biological Control:** Promote habitat diversification (flower strips, refugia) to support robust natural enemy populations despite climatic shifts.
4. **Climate-Smart IPM:** Tailor integrated pest management with climate forecasts to optimize timing of biological interventions.

### Conclusion

As climate change progresses, the synchrony between insect pests and their natural enemies is increasingly under threat, posing a major challenge to sustainable agriculture in India. Addressing this issue requires interdisciplinary research, climate-responsive pest management, and strengthened extension services to safeguard crop productivity and ecological balance.

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## Role of Biotechnology in Improving Silk Production

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### Introduction

Sericulture is an agro-based farming business that provides support for the rural livelihoods. The combination of growing mulberries, raising silkworms, making cocoons, and processing silk brings together farming and small business. India is one of the biggest silk manufacturers in the world next to China. The long-term success of this enterprise depends on silkworm health, mulberry leaf yield, and quality silk. Despite having successful tenure of sericulture in India; however, it has a lot of problems. Silkworms can get sick, the weather is often bad, the soil is getting worse, and the quality of mulberry leaves can change. Farmers often lose crops and money because of these things. Traditional solutions focus mainly on prevention, rather than curative measures. Conventional methods like breeding solves this problem by developing disease resistant, climate resilient and high yielding silkworms and mulberry plant, but it requires huge amount of time to develop these kinds of breeds.

In this situation, biotechnology has become an important scientific tool for sericulture. Biotechnology uses modern biological tools and methods to help us understand the genetic and physiological systems of mulberry trees and silkworms. This information is used to make silk production more efficient, disease-resistant, and of better quality. Biotechnology does not replace traditional sericulture methods; instead, it improves them by giving them accurate and long-lasting answers. Biotechnology has made it possible to improve mulberry varieties, create strong silkworm strains, find diseases early, and make silk of higher quality. These improvements lead to more cocoons being made, silk being worth more on the market, and sericulture producers having more stable jobs.

In sericulture, biotechnology is applied at different stages, including:

- i. Mulberry improvement (Enhance leaf yield & Nutritional quality, Developing disease and pest resistant mulberry varieties)
- ii. Silkworm improvement (Increase survival rate & cocoon weight, climate resilient breeds, disease resistant breeds)
- iii. Disease diagnosis, for early and accurate detection of infections (Grasserie, Pebrine, Flacherie and Muscardine)

### Improvement of Silkworm Breeds through Biotechnology

The productivity of silkworms is significantly influenced by genetics, environmental factors, and their ability to resist disease. Although traditional silkworm breeds are adapted to their local environments, they often show issues like sensitivity to temperature changes, vulnerability to illnesses, and inconsistent cocoon production. Moreover, the process of developing new breeds via traditional breeding is time-consuming. Biotechnology has provided novel methods to overcome these limitations by enhancing silkworm breeds with greater precision and efficacy. Biotechnology tools namely, genome editing, genetic engineering, RNA interference helps in finding solutions for the existing problems. Biotechnology offers researchers a means to examine the genetic and phenotypic attributes that govern silkworm growth, development, and silk output. This approach enables the identification of beneficial traits, including accelerated larval growth, greater cocoon weight, longer filament length, and improved survival rates in challenging environments. These improvements help farmers achieve more stable and predictable yields. Silkworms with better



tolerance to heat and diseases reduce crop failure, especially during unfavorable seasons. As a result, farmers can rear silkworms with greater confidence and reduced risk. Overall, biotechnology-assisted improvement of silkworm breeds strengthens the foundation of sericulture by ensuring healthier worms, better cocoon quality, and increased silk productivity, while maintaining the biological integrity of the silkworm.

### **Biotechnology in Disease Diagnosis and Management**

In sericulture, crop loss is often caused by diseases. Therefore, early and accurate diagnosis is essential for successful silkworm production. Biotechnology has strengthened disease management by enabling detection of infections at an early stage, often before visible symptoms appear. Microscopic examination is a basic and widely used method, especially for detecting microsporidian infections such as pebrine. Routine microscopic examination of silkworms and their eggs is essential for curtailing the propagation of diseases across generations. The Polymerase Chain Reaction (PCR) serves as a molecular method for identifying the specific genetic material associated with pathogenic organisms. This technique facilitates precise infection identification, even when pathogen levels are minimal, thereby bolstering disease surveillance efforts. Furthermore, Real-time PCR (qPCR) enhances diagnostic capabilities by enabling the assessment of infection severity, which, in turn, aids in monitoring disease progression and informing timely management strategies. Conversely, Loop-Mediated Isothermal Amplification (LAMP) offers a rapid and accessible diagnostic approach, making it particularly advantageous for deployment in field-based laboratories. This method facilitates the generation of prompt and dependable results, obviating the necessity for intricate instrumentation. Concurrently, recent developments have yielded CRISPR-based diagnostics, which provide exceptionally accurate and expeditious pathogen detection. While these tools are still in the process of becoming standard practice within sericulture, they exhibit considerable promise for future point-of-care disease diagnosis.

Consequently, the implementation of biotechnological diagnostic tools fosters early intervention, mitigates crop losses, and contributes to the promotion of healthier and more sustainable silkworm rearing practices.

### **Enhancement of Silk Quality through Biotechnology**

The quality of silk affects its market value. This is because of things like filament length, strength, fineness, uniformity, and reelability. Biotechnology has helped us learn more about the biological processes that go into making silk proteins and cocoons, which has made it possible to improve these quality traits. The dissection of silk-producing genes, specifically fibroin and sericin genes, has been elucidated. Scientific research on the biology and genetics of silkworms has led to the creation of silkworm lines that have heavier cocoon shells, stronger filaments, and higher raw silk recovery rates. Biotechnology also helps reduce defects caused by stress and disease, which makes the silk threads more even when they are being reeled. The fact that silkworms can better adapt to changes in their environment also helps to keep the quality of silk the same all year round. Advanced research is also looking into how to make value-added silk for special uses. This shows how biotechnology could improve the quality and economic value of silk.

### **Future Prospects**

The influence of biotechnology on sericulture is poised for further expansion, contingent upon ongoing research endeavors and enhanced technology dissemination. Molecular breeding techniques, coupled with swift disease diagnostics and the cultivation of stress-resistant mulberry and silkworm strains, will contribute to mitigating evolving obstacles, including those posed by climate change and escalating disease prevalence. Field-deployable diagnostic tools and precision-focused improvement methods are expected to enhance disease management strategies and increase productivity in agriculture. Moreover, biotechnology is projected to enable the development of value-



added silk products and improve overall efficiency within the sericulture value chain, thus supporting income stability and long-term sustainability.

Role of biotechnology in improving silk production



**Figure 1.** Role of biotechnology in improving silk production through mulberry improvement, silkworm improvement, and early disease diagnosis, leading to improved cocoon yield, better silk quality, and enhanced farmer income.

### Conclusion

Biotechnology has emerged as a crucial element in contemporary sericulture, facilitating advancements in mulberry cultivation, the enhancement of silkworm strains, the prompt identification of diseases, and the improvement of silk quality. When combined with efficient rearing methodologies and strong extension services, biotechnological applications contribute to mitigating production uncertainties while simultaneously augmenting both cocoon yield and quality. Using biotechnology carefully and with farmers' needs in mind will be crucial for the sustainable growth of the sericulture industry. This approach will also help improve the economic and social conditions of those involved in sericulture.



## Effects of Mulch Application on Soil-Dwelling Pest Populations

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Mulching refers to the surface placement of organic residues around crop plants, which functions to conserve soil moisture by reducing evaporation, suppress weed establishment, and moderate soil temperature, thereby offering frost protection to the root zone. Mulches may promote plant tolerance to the attack of insect pests because they can help to maintain soil moisture and temperature required for plant vigor.

### Effect of Different Mulching Types on Insect Pests and Pathogens

Type of Mulch	Crop / Plant	Insect Pest / Pathogen	Observed Effect	Source
Living mulch	Red clover (with cabbage)	Turnip root fly <i>Delia floralis</i> (Fallén, 1824)	Significant reduction in egg-laying activity	Björkman et al. (2010)
Straw mulch	Kale ( <i>Brassicaceae</i> )	Green peach aphid <i>Myzus persicae</i>	Reduced aphid population and improved refuge for natural enemies	Silva-Filho et al. (2014); Mochiah & Baidoo (2012)
Plastic mulch	Okra ( <i>Abelmoschus esculentus</i> (L.) Moench)	Flea beetles ( <i>Podagrica</i> spp.), cotton leaf roller ( <i>Notarcha derogata</i> ), cotton stainer ( <i>Dysdercus</i> spp.), Nigerian grasshopper <i>Oedaleus nigeriensis</i> Uvarov, 1926, whitefly <i>Bemisia tabaci</i> (Gennadius, 1889)	Reduction in insect pest incidence and increased crop yield	Ojiako et al. (2018)
Cowpea live mulch	Pepper ( <i>Capsicum annuum</i> L.)	Aphids ( <i>Aphis gossypii</i> Glover, 1877), thrips ( <i>Thrips tabaci</i> Lindeman, 1889), whiteflies ( <i>Bemisia tabaci</i> (Genn., 1889))	Suppression of pest populations	Mochiah & Baidoo (2012)
Living mulch	Eggplant ( <i>Solanum melongena</i> L.)	Colorado potato beetle <i>Leptinotarsa decemlineata</i> Say, 1824; flea beetles ( <i>Epitrix</i> spp.)	Lower numbers of adults, larvae, and eggs compared to monoculture	Hooks et al. (2013)
Organic mulches (straw, walnut leaves, mixed leaves, compost)	Potato ( <i>Solanum tuberosum</i> L.)	Soil-dwelling pests and soil-borne pathogens (e.g., <i>Fusarium</i> spp.)	Thick mulch layers ( $\geq 20$ cm) reduced tuber damage caused by pathogens	Südiné Fehér & Zalai (2024)

Green plastic mulch	Tomato, cucumber, watermelon, strawberry, vine, blueberry	Fungevorous nematodes ( <i>Aphelenchus</i> spp.), omnivorous nematodes (Dorylaimida), bacterial feeders (Rhabditida)	Minimal differences in nematode populations; long-term use showed no significant adverse effects	Pedra et al. (2024)
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Vegetable crops are highly vulnerable to damage caused by insect pests, making effective pest management essential for sustainable production. Several studies have demonstrated that mulching practices significantly influence pest distribution and abundance in agricultural systems. Straw mulching, in particular, has been shown to alter pest dynamics in cropping fields (Phophi and Mafongoya, 2017). Both organic and inorganic mulching materials exert distinct effects on soil-dwelling and foliar insect populations. For example, the application of straw mulch has been reported to increase insect abundance under certain conditions (Ma et al., 2021).

Rice straw mulch has been found to enhance the presence and activity of natural enemies, thereby contributing to biological pest regulation, whereas black polythene mulch suppresses insect pest populations more effectively (Kumaratenna et al., 2022). Organic mulches such as fruit peels and rice straw modify the soil microclimate by influencing temperature and ultraviolet radiation, which in turn reduces aphid infestation levels (Silva-Filho et al., 2014). Plastic mulching has also been recommended for achieving higher crop productivity and effective insect pest management in okra (*Abelmoschus esculentus* (L.) Moench) cultivation (Ojiako et al., 2018).

In pepper production systems, straw mulch provides a favourable habitat for natural enemies and remains a viable pest management option, while cowpea mulch has been reported to be more effective in directly suppressing pest populations (Mochiah and Baidoo, 2012). Overall, mulching contributes to reduced pest pressure and crop damage by enhancing natural enemy activity, improving soil micro-environmental conditions, and disrupting pest

development and survival (Gill et al., 2011; Thomson and Hoffmann, 2007).

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## Irrigation: An Effective and Eco-Friendly Tool for Pest Management in Mulberry Gardens

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Mulberry cultivation is the backbone of sericulture, as the quality of mulberry leaves directly determines the growth, health, and cocoon yield of silkworms. Farmers generally depend on fertilizers and pesticides to improve leaf production and control pests. However, among the various agronomic practices, irrigation plays a very important but often underestimated role in pest management. Proper irrigation not only supports plant growth but also strengthens the plant's natural ability to withstand insect attack.

Pest incidence in mulberry gardens is closely linked with plant health and moisture availability. When mulberry plants suffer from water stress, their growth becomes weak and irregular. Such stressed plants produce tender, nutrient-imbalanced leaves, which attract several insect pests. Dry and dusty conditions further favor the multiplication of sap-sucking pests such as aphids, thrips, mites, and whiteflies. Therefore, improper or irregular irrigation often leads to increased pest problems in mulberry gardens.

Adequate irrigation helps mulberry plants maintain vigorous growth and better physiological balance. Well-watered plants develop strong shoots, thicker leaf cuticles, and improved nutrient uptake from the soil. These characteristics make mulberry leaves less attractive and less suitable for pest feeding and reproduction. Healthy plants also recover faster from minor pest damage, thereby reducing the overall impact of insect infestation.

Irrigation also influences the microclimate within the mulberry garden. Many insect pests prefer hot, dry, and dusty environments for rapid multiplication. Proper irrigation lowers soil and canopy temperature, increases soil moisture, and reduces dust accumulation on leaf surfaces. These changes create

an unfavorable environment for pests such as mites and thrips, which thrive under dry conditions. As a result, pest population buildup is naturally suppressed.

In addition to improving plant health and microclimate, irrigation can directly reduce pest numbers by physically removing insects from plant surfaces. Sprinkler irrigation, in particular, helps wash away early stages of pests such as aphids, whiteflies, and mites from leaves. This mechanical reduction is especially useful during the initial stages of infestation, preventing pests from reaching damaging levels.

Another important benefit of proper irrigation is its positive influence on beneficial insects. Natural enemies like ladybird beetles, lacewings, spiders, and predatory mites play a vital role in regulating pest populations in mulberry gardens. These beneficial organisms prefer moist and shaded environments, which are more common in well-irrigated fields. By supporting natural enemies, irrigation indirectly strengthens biological pest control.

Different methods of irrigation can be effectively used for pest management in mulberry cultivation. Traditional flood irrigation helps reduce mite and thrips populations during summer by maintaining adequate soil moisture. Furrow irrigation ensures uniform moisture distribution without excessive wetting of foliage. Sprinkler irrigation is useful for washing pests off leaves, while drip irrigation provides continuous soil moisture, reducing plant stress and pest susceptibility. Selection of irrigation method depends on soil type, water availability, and season.

The timing and frequency of irrigation also play a crucial role in pest suppression. During summer



months, frequent irrigation at shorter intervals prevents moisture stress and reduces the chances of pest outbreaks. In cooler seasons, moderate irrigation helps maintain plant vigor without causing excessive humidity. However, care must be taken to avoid waterlogging, as excessive moisture can lead to root diseases and indirectly weaken plants.

Field observations from major mulberry-growing regions indicate that gardens receiving regular and timely irrigation experience lower pest incidence compared to poorly irrigated fields. Farmers have reported reduced aphid and mite populations, improved leaf tenderness, and better silkworm feeding efficiency. Many growers also observed a decrease in pesticide usage after adopting proper irrigation schedules, leading to safer leaves for silkworm rearing.

From an economic and environmental perspective, irrigation-based pest management offers several advantages. It is a low-cost, eco-friendly practice that reduces dependence on chemical pesticides. Since mulberry leaves are directly fed to silkworms, minimizing pesticide residues is essential. Proper irrigation ensures safer leaf production while maintaining high productivity and sustainability in sericulture.

In conclusion, irrigation should be considered not only as a water management practice but also as a powerful cultural tool for pest management in mulberry gardens. By maintaining plant health, modifying the garden microclimate, and supporting natural enemies, irrigation helps suppress pest populations in a natural and sustainable manner. Integrating proper irrigation practices into mulberry cultivation can significantly improve leaf quality, reduce pest problems, and enhance overall sericulture productivity.



**Figure 1.** Role of irrigation in pest management of mulberry gardens. Proper irrigation improves plant Vigor, creates a favourable microclimate, and enhances the activity of natural enemies, collectively resulting in reduced pest incidence, improved leaf quality, and better silkworm performance.

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# Harnessing Plant Based Additives For Optimizing Animal Production And Welfare

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Farm animal populations are being continually improved through selective breeding to enhance the economic efficiency of animal production, with nutrition recognized as a critical contributing factor (Svitakova et al., 2014). In this context, phytogetic feed additives have emerged as a promising natural alternative due to their ability to support various biological processes in animals. These plant-derived substances are known to improve feed quality, promote animal health, and enhance the quality of animal products through their active compounds. Phytogetic additives are typically categorized into four groups: sensory additives that influence the taste and aroma of animal products; technological additives such as antioxidants and agents that reduce mycotoxin levels in feed; zootechnical additives, including immune boosters, digestive aids, and non-microbial growth promoters; and nutritional additives, such as vitamins, minerals, and plant-based enzymes. Although they are mainly used as sensory, technological, and zootechnical additives, many phytogetic substances have multiple beneficial effects and cannot be strictly classified into a single category.

## Sensory additives

Sensory additives, particularly natural and synthetic colourants, are widely used in poultry diets to enhance egg yolk pigmentation, a key quality trait influencing consumer preference (Englmaierova et al., 2014). Laying hens cannot synthesize yolk pigments, so their colour depends on dietary xanthophylls. Synthetic pigments like canthaxanthin are cost-effective but raise health concerns if used excessively. Natural alternatives, such as carotenoids from marigold, carrots, *Chlorella*, and lutein, are preferred but can be costly and unstable. *Chlorella* supplementation notably increased yolk carotenoid

levels and colour, though high doses may reduce yolk weight (Kotrbaek et al., 2013). Additional carotenoids like astaxanthin also provide antioxidant and health benefits (Zhang et al., 2014).

## Technological additives

Phytogetic feed additives are increasingly being investigated for their potential to reduce harmful gas emissions in livestock. In pigs, additives such as oregano oil and various plant powders can significantly reduce odorous compounds like ammonia (NH<sub>3</sub>-N) and hydrogen sulfide (H<sub>2</sub>S) (Alam et al., 2013). Specifically, oregano addition led to the complete absence of these gases and altered the microbial population, suggesting a strong deodorizing effect. Similarly, in pig housing, reductions in ammonia emissions by 32–38% using *Quillaja saponaria* extracts (Veit et al., 2011), and lowers ammonia levels in broiler chickens by feeding essential oils including oregano and citrus peel (Hong et al., 2012). In ruminants, methane (CH<sub>4</sub>) a major greenhouse gas can be reduced using various phytogetic substances. *Artemisia annua* extract, Siberian fir and clove oils, and herbal mixtures significantly lowers the methane production (Cieslak et al., 2014). Saponins, especially from sources like yucca and quillaja, also effective, though their impact depends on the source and dosage (Jayanegara et al., 2014).

## Zootechnical additives

### Immunomodulators

Phytogetic feed additives (PFAs) are increasingly recognized for their immunomodulatory properties in livestock, poultry, aquaculture, and even beekeeping. A key group of immunostimulants includes  $\beta$ -glucans, mainly sourced from fungi and yeast like



*Saccharomyces cerevisiae*, and to a lesser extent from cereals or seaweed. New sources such as bamboo leaf extract have shown promise in boosting immune cell activity, notably CD8<sup>+</sup> T-cells in cattle (Ohtsuka et al., 2014). Therapeutic antibodies targeting  $\beta$ -glucans are also being developed using plants like *Nicotiana benthamiana*.

**Essential oils** are widely used for their antimicrobial and antioxidant effects with minimal harm to host animals. In broilers, PFAs containing thyme improve growth and gut health while inhibiting *Clostridium perfringens* and *E. coli* (Cho et al., 2014). *Salvia officinalis* oil enhance antioxidative status and blood phagocyte activity in chicks and sucrose esters of capric and lauric acids showed strong antimicrobial action.

In pigs, essential oils from turmeric, oregano, thyme, and rosemary, as well as sulforaphane from broccoli, enhance the antioxidant system and improve health status despite no major changes in gut microflora. Phytochemicals may also influence pig fertility, a key factor in swine production (Kapelanski et al., 2013).

### **Substances increasing production performance or animal product quality**

Phytogenic feed additives (PFAs), which include herbs, plant extracts, essential oils, and spices, are increasingly used in animal nutrition as natural alternatives to antibiotics. In poultry, PFAs such as turmeric, thyme, oregano, peppermint, and sumac have been shown to improve growth, feed efficiency, egg production, antioxidant status, and meat and egg quality. In pigs, they help to reduce diarrhea, support immune function, and improve growth. Similar positive effects have been observed in lambs, rabbits, and fish, including better immune response, improved meat quality, and reduced disease-related mortality. Overall, while outcomes can vary based on the animal species, type of additive, and dosage used, PFAs offer a promising natural tool to enhance animal health, performance, and the quality of animal products.

### **Substances decreasing the negative effects of stress factors**

Oxidative stress, caused by an imbalance between reactive oxygen species (ROS) production and inactivation, is a key factor in chronic diseases affecting both humans and animals. Phytogenic additives have been known for their protective antioxidant effects against such stress. Bilberry extract reduced ROS levels and oxidative DNA damage in cells; *Celosia cristata* extract protected rat liver cells from chemically induced oxidative damage by lowering harmful enzymes and lipid peroxidation; and *Buddleja cordata* extract showed neuroprotective effects in a Parkinson's disease rat model by preserving dopamine and reducing oxidative damage. Additionally, thymol supplementation in Japanese quail helps to reduce fear responses by modulating GABA receptors, and evening primrose oil improve antioxidant status and reduce muscle cell damage in racehorses under training.

### **Conclusion**

Phytogenic feed additives represent a valuable and versatile natural strategy to improve animal nutrition, health, and production efficiency. Their diverse bioactive compounds contribute to enhancing sensory qualities, reducing environmental pollutants, modulating immune responses, boosting growth and product quality, and mitigating the harmful effects of stress through antioxidant mechanisms. While the effectiveness of these additives depends on factors such as species, dosage, and specific compounds used, the growing body of research supports their potential as sustainable alternatives to synthetic additives and antibiotics in animal agriculture. Continued investigation and careful application of phytogenic additives will further optimize their benefits, contributing to healthier animals, better product quality, and more environmentally friendly livestock production systems.

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# Modern and Sustainable Soil Management Practices: Building the Foundation for Future Agriculture

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Soil is the foundation of agriculture, yet it remains one of the most neglected natural resources. For decades, intensive cultivation, excessive tillage, monocropping, indiscriminate fertilizer use, and climate stress have steadily degraded soil health across many regions of India. Declining organic carbon, nutrient imbalance, compaction, erosion, and reduced biological activity now threaten long-term productivity. Modern and sustainable soil management practices have therefore become essential, not only to maintain crop yields but also to ensure environmental protection, climate resilience, and economic stability for farmers.

## Concept of Sustainable Soil Management

Sustainable soil management is the integrated use of land, water, and biological resources to maintain soil productivity while preventing degradation. It emphasizes long-term soil health rather than short-term yield maximization. Modern approaches view soil as a living ecosystem that must be nurtured through balanced physical, chemical, and biological management. These practices aim to improve soil structure, enhance nutrient cycling, increase water-holding capacity, and sustain microbial activity, ensuring soils remain productive for future generations.

## Conservation Agriculture: Protecting Soil Structure and Function

Conservation agriculture is a cornerstone of sustainable soil management. It is based on minimum soil disturbance, permanent soil cover, and diversified cropping systems. Excessive tillage breaks down soil aggregates, accelerates organic matter loss, and increases erosion. Reduced or zero tillage preserves soil structure, enhances infiltration,

and protects soil organisms. Crop residues left on the surface act as mulch, reducing temperature extremes, minimizing evaporation, and preventing erosion. Crop rotation improves soil fertility and reduces pest and disease pressure, creating a more balanced soil environment.

## Organic Matter Management: The Key to Soil Vitality

Soil organic matter plays a critical role in maintaining soil fertility, structure, and biological health. Modern sustainable practices promote regular addition of organic inputs such as farmyard manure, compost, green manure, crop residues, vermicompost, and biochar. Organic matter improves aggregation, enhances water retention, and increases nutrient availability. It also serves as food for soil microorganisms, which drive nutrient cycling. Increasing soil organic carbon is particularly important under climate change, as it improves soil resilience to droughts and floods while contributing to carbon sequestration.

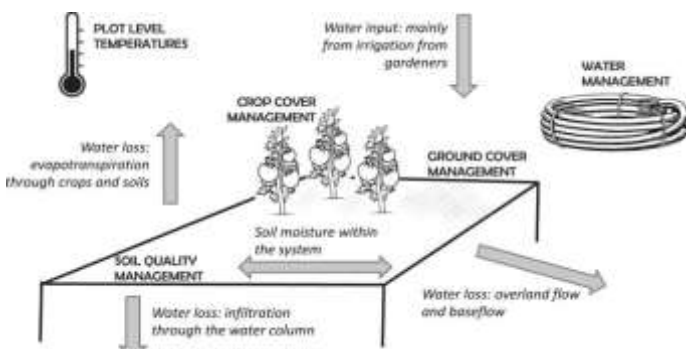


## Integrated Nutrient Management: Balancing Productivity and Sustainability

Integrated Nutrient Management (INM) focuses on the judicious use of chemical fertilizers in combination with organic and biological sources.



Overuse of chemical fertilizers can lead to nutrient imbalance, soil acidity or salinity, and reduced microbial activity. INM ensures that nutrients are supplied in the right quantity, form, and timing, improving nutrient-use efficiency. Biofertilizers such as nitrogen-fixing bacteria, phosphate-solubilizing microorganisms, and mycorrhizae enhance nutrient availability naturally, reducing dependence on synthetic inputs and maintaining long-term soil fertility.



### Soil Moisture Conservation and Climate Adaptation

Soil moisture conservation is increasingly important as rainfall becomes erratic and dry spells intensify. Practices such as mulching, cover cropping, conservation tillage, contour farming, and ridge-and-furrow systems help retain moisture in the root zone. Organic mulches moderate soil temperature, suppress weeds, and reduce evaporation losses. Improved soil structure and higher organic matter content increase the soil's capacity to store water, allowing crops to withstand short-term drought stress and improving yield stability under climate variability.

### Precision Soil Management and Digital Technologies

Modern soil management increasingly relies on digital tools and precision agriculture techniques. Soil testing, soil health cards, digital soil maps, remote sensing, and GPS-based nutrient application enable site-specific management. Precision soil management avoids blanket fertilizer application and tailors inputs according to soil variability within fields. This reduces input costs, minimizes nutrient

losses, and prevents environmental pollution. Data-driven soil management supports informed decision-making and helps monitor soil health trends over time.

### Soil Biology and Microbial Diversity

Soil is a biologically active system, home to billions of microorganisms that regulate nutrient cycling, organic matter decomposition, and disease suppression. Sustainable practices aim to enhance microbial diversity by reducing chemical stress, increasing organic inputs, and maintaining soil cover. Healthy microbial populations improve nutrient availability, promote root growth, and enhance soil resilience. Biological soil health is increasingly recognized as critical for sustainable productivity, particularly under stress conditions.

### Agroforestry and Diversified Cropping Systems

Agroforestry integrates trees with crops and livestock, offering long-term benefits for soil health. Tree roots improve soil structure, reduce erosion, and recycle nutrients from deeper soil layers. Leaf litter adds organic matter and protects the soil surface. Diversified cropping systems reduce soil nutrient depletion and improve ecosystem stability. Such systems also enhance biodiversity and reduce vulnerability to climate extremes.

### Soil Carbon Sequestration and Climate Mitigation

Soils are one of the largest terrestrial carbon reservoirs. Sustainable soil management increases soil organic carbon, helping mitigate climate change by capturing atmospheric carbon dioxide. Practices such as residue retention, reduced tillage, cover cropping, and organic amendments enhance carbon storage. Carbon-rich soils are more fertile, retain more water, and are more resilient to climate stress, creating a positive feedback between soil health and climate adaptation.

### Challenges in Adoption of Sustainable Practices

Despite proven benefits, adoption of sustainable soil practices faces constraints. Farmers often prioritize



immediate yields over long-term soil health. Limited awareness, lack of technical guidance, initial investment costs, and risk perception slow adoption. Small and marginal farmers are particularly vulnerable. Overcoming these barriers requires strong extension services, policy incentives, access to credit, and demonstration of long-term economic benefits.

### Role of Policy, Education, and Institutions

Government policies play a critical role in promoting sustainable soil management. Soil health card schemes, incentives for organic inputs, promotion of micro-irrigation, and support for conservation agriculture are important steps. Agricultural education and capacity-building programs help farmers understand soil processes and adopt better practices. Institutional support ensures that soil conservation becomes an integral part of agricultural planning rather than an optional activity.

### Future Outlook: Soil-Centered Agricultural Development

The future of agriculture depends on recognizing soil as a strategic natural resource. Sustainable soil management must be integrated with water management, climate adaptation strategies, and food security policies. Advances in soil science, digital tools, and biological inputs offer new opportunities to restore degraded soils. Long-term investment in soil health will yield benefits in productivity, resilience, and environmental sustainability.

### Conclusion: Investing in Soil Is Investing in the Future

Modern and sustainable soil management practices offer a pathway to productive, resilient, and environmentally responsible agriculture. By improving soil health through conservation

agriculture, organic matter management, precision technologies, and biological approaches, farmers can secure stable yields while protecting natural resources. Healthy soils are the foundation of food security, climate resilience, and rural prosperity. Protecting soil today ensures a sustainable tomorrow.

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# From Field to Feed: How Media Narratives Shape the Image of Rural Indian Farmers

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India's rural farmers have long stood at the heart of the nation's economy, culture, and food security. Yet, for decades, their image in mainstream media has oscillated between extremes — from the romanticized “son of the soil” to the distressed figure burdened by debt and uncertainty. In recent years, however, media narratives have begun to evolve, offering a more layered, empowering, and future-oriented portrayal of rural Indian farmers. This shift matters deeply, because how farmers are represented in media shapes public perception, policy discourse, and even farmers' own sense of identity.

## The Power of Media in Constructing Rural Images

Media does more than report reality — it actively constructs meaning. Communication scholars argue that repeated frames and narratives influence how audiences interpret social groups and issues (McCombs & Shaw, 1972). In the Indian context, rural farmers have often been framed through lenses of crisis: crop failure, farmer suicides, climate stress, or political agitation. While these issues are real and deserve attention, an over-reliance on distress narratives can unintentionally reduce farmers to passive victims rather than active agents of change.

Recent trends across print, digital platforms, documentaries, and social media, however, indicate a growing effort to rebalance this image — highlighting resilience, innovation, and adaptation in rural India.

## From Margins to Mainstream: Emerging Positive Narratives

One of the most encouraging developments in Indian media is the visibility of farmer-entrepreneurs and

agri-innovators. Stories of farmers adopting organic practices, precision farming, solar irrigation, and digital marketplaces are increasingly featured in newspapers, television features, and online platforms.

Initiatives like e-NAM (National Agriculture Market) and Farmer Producer Organizations (FPOs) are frequently showcased as success stories, illustrating how farmers are leveraging technology and collective bargaining to improve incomes and market access (Ministry of Agriculture & Farmers Welfare, Government of India).

Media platforms such as The Hindu, Down To Earth, Mongabay India, and BBC India have played a crucial role in presenting nuanced rural reporting — blending ground realities with data, policy context, and farmer voices themselves. This shift aligns with participatory communication models that emphasize representation with communities rather than about them.

## Social Media: Farmers as Storytellers

Perhaps the most transformative change has come from social media. Farmers today are no longer just media subjects; many are content creators. Through YouTube channels, Instagram reels, and WhatsApp groups, rural farmers share crop practices, weather updates, price information, and lived experiences directly with audiences.

These platforms challenge traditional gatekeeping in media and allow farmers to frame their own narratives — showcasing pride in their work, local knowledge, and cultural identity. According to a FAO report on digital agriculture, such platforms enhance visibility, peer learning, and rural



empowerment when supported by digital literacy initiatives (FAO, 2022).

### **Cinema, Advertising, and Cultural Representation**

Indian cinema and advertising have also contributed to reshaping the farmer’s image. Recent films and brand campaigns increasingly depict farmers as knowledgeable, adaptive, and environmentally conscious rather than outdated or helpless. Advertisements promoting sustainable farming tools, insurance schemes, and agri-tech solutions often portray farmers as decision-makers and innovators — subtly influencing public respect toward the profession.

Cultural representation matters because symbolic portrayals can reinforce dignity and social value, especially for occupations historically undervalued in urban narratives.

### **Why Positive Representation Matters**

#### **Positive and balanced media narratives have tangible social impact:**

- **Public Perception:** Urban audiences gain a more respectful and realistic understanding of rural life.
- **Policy Attention:** Constructive media framing encourages solution-oriented policy debates rather than reactive responses.
- **Youth Engagement:** When farming is shown as skilled, modern, and meaningful, rural youth are more likely to see agriculture as a viable future.
- **Farmer Self-Identity:** Media validation can strengthen confidence and collective morale within farming communities.

As communication theorist Stuart Hall emphasized, representation is closely tied to power — who is seen, how they are seen, and who gets to tell the story (Hall, 1997).

### **Towards Responsible and Inclusive Rural Storytelling**

While progress is visible, the journey is ongoing. Responsible rural journalism must continue to avoid stereotypes — both negative and overly romanticized — and instead embrace complexity. Farmers are not a monolithic group; they differ by region, gender, caste, landholding, and access to resources. Including women farmers, indigenous practices, and marginal voices remains a critical task for Indian media.

Collaborations between journalists, academic researchers, agricultural institutions, and rural communities can further strengthen authentic storytelling — ensuring that narratives from the field reach the feed with accuracy, empathy, and respect.

From traditional fields to digital feeds, the image of the Indian farmer is being renegotiated in powerful ways. Media narratives that recognize farmers as innovators, custodians of the environment, and contributors to national resilience help bridge the rural-urban divide and reaffirm agriculture’s central place in India’s future.

When media listens more closely to the soil — and to those who work it — the stories that emerge are not just about survival, but about strength, dignity, and possibility.



# Climate Smart Agriculture Practices: A Sustainable Approach for Future Farming

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Agriculture remains the backbone of rural livelihoods and food security across the world, particularly in developing countries like India. Millions of farmers depend on agriculture not only for income but also for sustaining their families and communities. However, agriculture is one of the most climate-sensitive sectors. Changes in temperature, rainfall variability, frequent droughts, floods, and rising pest and disease incidence are creating serious challenges for farmers. Climate change is no longer a distant threat; it is a present reality affecting agricultural productivity and sustainability. In this context, Climate Smart Agriculture (CSA) has emerged as a comprehensive and practical approach to ensure sustainable agricultural development while addressing climate-related challenges.

## Understanding Climate Smart Agriculture

Climate Smart Agriculture refers to agricultural practices that sustainably increase productivity, enhance farmers' resilience and adaptive capacity to climate change, and reduce greenhouse gas emissions wherever possible. The concept was introduced by the Food and Agriculture Organization (FAO) to promote integrated solutions for climate-related agricultural problems.

CSA is based on three main pillars. The first pillar focuses on increasing agricultural productivity and farmers' income. The second pillar aims to strengthen the resilience of agricultural systems to climate variability and extreme weather events. The third pillar emphasizes reducing greenhouse gas emissions from agricultural activities. By integrating these three objectives, CSA promotes environmentally sustainable and economically viable farming practices.

## Need for Climate Smart Agriculture

The agricultural sector is increasingly facing unpredictable weather patterns. Irregular monsoon rainfall, prolonged dry spells, and sudden heavy rainfall events have disrupted traditional cropping systems. Rising temperatures are affecting crop growth and yield quality. Climate change is also increasing the spread of pests and diseases, which further reduces crop productivity.

Small and marginal farmers are particularly vulnerable to climate change because they have limited access to irrigation, technology, and financial resources. Climate Smart Agriculture provides practical solutions that help farmers adapt to changing climatic conditions while maintaining stable crop production and income security.

## Crop Diversification and Improved Cropping Systems

Crop diversification is one of the most effective strategies in Climate Smart Agriculture. It involves cultivating multiple crops instead of relying on a single crop. Diversification reduces the risk of complete crop failure due to unfavorable climatic conditions such as drought or floods. It also improves soil fertility and enhances farm biodiversity.

Farmers can adopt intercropping, mixed cropping, and crop rotation practices to improve resource utilization and maintain soil health. For example, growing legumes along with cereals helps in improving soil nitrogen levels. Crop rotation also breaks pest and disease cycles, reducing dependence on chemical pesticides. Diversified cropping systems provide farmers with multiple income sources and reduce economic risks.



### **Efficient Water Resource Management**

Water scarcity is becoming one of the most serious challenges in agriculture due to climate change. Efficient water management plays a crucial role in Climate Smart Agriculture. Adoption of modern irrigation techniques such as drip irrigation and sprinkler irrigation helps in conserving water and improving irrigation efficiency. These methods deliver water directly to plant roots, reducing water loss through evaporation and runoff.

Rainwater harvesting and construction of farm ponds help in storing rainwater for irrigation during dry periods. Proper drainage systems are equally important in flood-prone areas to prevent waterlogging and crop damage. Conservation practices such as mulching help in maintaining soil moisture and reducing water requirements. Efficient water management not only improves crop productivity but also ensures sustainable use of water resources.

### **Soil Health Management and Conservation Agriculture**

Healthy soil is the foundation of sustainable agriculture. Climate Smart Agriculture emphasizes improving soil health through integrated nutrient management and conservation practices. Regular soil testing helps farmers understand the nutrient status of their soil and apply fertilizers in balanced quantities. Overuse of chemical fertilizers can degrade soil quality and increase greenhouse gas emissions.

Incorporating organic manure, green manure, compost, and crop residues improves soil organic matter and enhances soil fertility. Conservation agriculture practices such as minimum tillage, zero tillage, and mulching help in reducing soil erosion, improving soil structure, and conserving soil moisture. These practices also reduce fuel consumption and labor costs, making farming more sustainable and cost-effective.

### **Adoption of Climate-Resilient Crop Varieties**

The development and adoption of climate-resilient crop varieties is an important component of Climate

Smart Agriculture. These improved crop varieties are designed to tolerate drought, salinity, floods, heat stress, and pest attacks. Climate-resilient varieties help farmers maintain stable production even under adverse climatic conditions.

Research institutions and agricultural universities are continuously developing new varieties that can withstand extreme weather conditions. Farmers should be encouraged to adopt these varieties to reduce production risks and improve yield stability. Timely availability of quality seeds is essential for successful implementation of this strategy.

### **Integrated Pest and Disease Management**

Climate change has increased the incidence and severity of pest and disease outbreaks in agricultural crops. Integrated Pest Management (IPM) is a climate smart approach that combines biological, cultural, mechanical, and chemical methods to control pests in an environmentally safe manner.

IPM practices include the use of resistant crop varieties, biological control agents, crop rotation, and proper field sanitation. Monitoring pest populations and using chemical pesticides only when necessary reduces environmental pollution and production costs. IPM helps in maintaining ecological balance and promotes sustainable crop protection.

### **Role of Agroforestry and Integrated Farming Systems**

Agroforestry is an important climate smart practice that involves growing trees along with crops and livestock. Trees improve soil fertility by adding organic matter and preventing soil erosion. They also provide shade, reduce wind speed, and help in carbon sequestration. Farmers can obtain additional income from timber, fruits, fodder, and fuelwood.

Integrated farming systems combine crop production with livestock, poultry, fisheries, and horticulture. This system ensures efficient utilization of farm resources and provides diversified income opportunities. Waste from one enterprise can be used as input for another, thereby reducing production costs and improving farm sustainability.



### Use of Modern Technologies and Climate Information Services

Technological advancement plays a significant role in Climate Smart Agriculture. Digital tools such as mobile applications, remote sensing, and geographic information systems provide farmers with real-time weather information and agricultural advisories. Weather-based advisory services help farmers make informed decisions regarding sowing, irrigation, fertilizer application, and pest management.

Precision agriculture technologies such as soil moisture sensors and automated irrigation systems improve resource use efficiency. Government and extension agencies are promoting digital agriculture to enhance farmers' access to climate information and improve farm management practices.

### Renewable Energy and Sustainable Farm Mechanization

Climate Smart Agriculture also promotes the use of renewable energy sources such as solar pumps, biogas plants, and wind energy for agricultural operations. Solar-powered irrigation systems reduce dependence on fossil fuels and lower greenhouse gas emissions. Biogas plants convert farm waste into clean energy and organic manure, contributing to sustainable farming.

Farm mechanization improves labor efficiency and reduces drudgery, particularly for women farmers. Climate-friendly agricultural machinery such as zero-till seed drills and residue management equipment supports conservation agriculture practices.

### Capacity Building and Extension Support

Successful implementation of Climate Smart Agriculture requires awareness and capacity building among farmers. Training programs, demonstrations, and farmer field schools help farmers understand and adopt climate smart practices. Agricultural extension services play a vital role in transferring climate-related knowledge and technologies to farmers.

Government policies and institutional support are essential for promoting CSA practices. Financial incentives, crop insurance schemes, and climate-resilient infrastructure development encourage farmers to adopt sustainable agricultural practices.

### Benefits of Climate Smart Agriculture

Climate Smart Agriculture provides multiple benefits. It enhances crop productivity and ensures food security. CSA practices improve farmers' resilience to climate change and reduce production risks. Sustainable soil and water management practices protect natural resources and maintain environmental balance. Adoption of CSA also helps in reducing greenhouse gas emissions and contributes to climate change mitigation.

Moreover, diversified farming systems increase farmers' income and improve rural livelihoods. Climate Smart Agriculture promotes long-term agricultural sustainability and supports the overall development of the agricultural sector.

### Challenges in Adoption of Climate Smart Agriculture

Despite its benefits, adoption of Climate Smart Agriculture faces several challenges. Limited awareness among farmers, lack of access to technology, financial constraints, and inadequate extension support hinder the adoption of CSA practices. Small and marginal farmers often hesitate to adopt new technologies due to risk and investment concerns.

Strengthening agricultural research, improving extension services, and providing financial and technical support can help overcome these challenges. Public-private partnerships and community-based approaches can also promote the widespread adoption of climate smart practices.

### Conclusion

Climate change poses a serious threat to global agriculture and food security. Climate Smart Agriculture provides an integrated and sustainable solution to address these challenges. By adopting



climate-resilient cropping systems, efficient water and soil management practices, modern technologies, and diversified farming systems, farmers can enhance productivity while protecting natural resources.

Promoting Climate Smart Agriculture requires coordinated efforts from farmers, researchers, policymakers, and extension agencies. Increased awareness, training, and policy support can

encourage farmers to adopt climate smart practices. In the long run, Climate Smart Agriculture will play a crucial role in ensuring sustainable agricultural development, improving farmers' livelihoods, and safeguarding the environment for future generations.

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## Pollinators in Peril: The Pesticides Types Targeting Non-Apis Bees

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Insects play major role in pollination. Pollination done by insects are known as Entomophily. Among insects Bees plays very crucial role, and pollination done by bees are known as Melittophily. When compared to other mode of Pollination, about 80-85% pollination done by bees. When compared to Honey bee, the pollination done by non-Apis bee have more crop yield than Honey bee. But the use of pesticides, as formulated products, and their active ingredients are regulated to ensure that products are effective in crop protection, and at the same time, safe for humans and the environment. Pesticide exposure is a growing concern for non-Apis bees, such as bumblebees, solitary bees (e.g., mason and leafcutter bees), and stingless bees, which are vital for pollinating wild plants and many agricultural crops. non-Apis bees encounter pesticides through direct contact during application, consumption of contaminated nectar and pollen, and residues in soil, water, or nesting materials. The impacts of pesticides, especially systemic ones like neonicotinoids, can include acute toxicity and various sub-lethal effects. Acute exposure can cause immediate mortality, while sub-lethal effects impair foraging behaviour, navigation, reproduction, bee behaviour and immune function. These effects can disrupt essential behaviours such as nest building and mating, leading to population declines.

### Notable non- Apis Bees Families:

- Apidae (Bumble Bees, Carpenter Bees)
- Megachilidae (Leaf Cutter and Mason Bees)
- Halictidae (Sweat Bees)
- Colletidae (Plasterer Bees)
- Andrenidae (Mining Bees)
- Melittidae (Melittid Bees)
- Stenotritidae (Swift Bees)

### Types of Pesticides:

- Insecticides
- Herbicides
- Fungicides

#### a) Insecticides:

Insecticides are used to control the pest population in agricultural field to increase the crop yield. It includes Acaricides, Nematicides also. Major group of insecticides that affect the non-Apis bees majorly are follows,

#### ❖ Neonicotinoid:

- These group of insecticides are widely used to control sucking pests in agricultural field.
- Due to its systemic action, it can easily penetrate into the plants and circulate throughout the plant body.
- Neonicotinoid used both in Seed treatment as well as in foliar spray application.
- Act on Central Nervous System (CNS). Nicotinic Acetyl Choline receptor competitive modulator.
- Cause disorientation, reduced foraging ability, mortality of bees.
- Imidacloprid affects Bumble bee Hibernation behavior by reducing the weight of the Queen bee, also impair the Foraging ability, Flower handling skills etc.



- Clothianidin affects and reduce the oocyte length of bees. And also induce the Protozoan namely *Nosema ceranae*.
- Insecticides like Thiamethoxam find that more sensitive to Solitary bees.
- Includes, Imidacloprid, Thiacloprid, Acetamiprid, Clothianidin, Thiamethoxam etc.
- Due to its negative consequences the European council ban to use of Imidacloprid and promote use of Flupyradifuran, Sulfoxaflor has same Mode of Action of Neonicotinoid, that causes less affect to the pollinators.

### ❖ Pyrethroids

- Compound that mimics Natural insecticides.
- It has high persistence nature. Due to its persistence nature, it easily contaminates the pollen and nectar of the plants flower which are essential for bees foraging.
- Has Mode of action of Sodium channel Modulator. Thus, sodium channels remain open, Rapid entry sodium ions causes neurotoxicity, paralysis etc.
- They can be harmful to bees, particularly when exposed during foraging.
- Stingless bees are more sensitive for pyrethroids.
- It includes, Cypermethrin, Permethrin, Deltamethrin etc.

### ❖ Organophosphates:

- Causes acute toxicity to bees that results, Death of bees.
- It affects the enzyme acetylcholinesterase.
- It also affects the memory capacity of the bees. Which causes bees fail to return colony after foraging.
- Organophosphate, Carbamates have similar mode of action and causes same affect to the bees.

- It includes, Chlorpyrifos, Quinalphos, etc.

### b) Herbicides:

- Used to control weeds in agricultural lands.
- Mode of action. 4Hydroxyphenylpyruvate dioxygenase inhibitors impair carotenoid biosynthesis, causing plant bleaching and subsequent death.
- Acetyl CoA carboxylase inhibitors prevent the normal metabolism of fatty acids.
- Also affect the availability of floral resources for foraging of bees.
- Stingless bee species oral ingestion resulted in paraquat inducing higher mortality for *Tetragonisca fiebrigi* and nicosulfuron inducing higher mortality in *Tetragonisca angustula*.
- In non-agricultural areas, 83.3% of pollen samples contained metolachlor; adjacent to untreated maize, 75% and 54% of pollen samples contained metolachlor and atrazine, respectively, and adjacent to treated maize, 34–87.5% of pollen samples contained metolachlor, atrazine, and acetochlor.
- It includes, Glyphosate, Metolachlor, etc.

### c) Fungicides:

- Fungicides are used to control fungal and mold growth in plants.
- Also cause indirect effect to the bees.
- It affects the immune system of the bees and make the bees susceptible to diseases and pests.
- It also has a synergistic effect with insecticides.
- It disturbs the gut micro biome of the bees.
- Sterol Biosynthesis Inhibitor, Demethylation Inhibitors are two types it affects the Cytochrome p450 mono-oxygenase enzyme in bees.
- Respiratory chain succinate dehydrogenase inhibitors of complex II impede respiratory



chain succinate dehydrogenase, while respiratory chain strobilurin -type quinone outside-site of complex III inhibitors inhibit mitochondrial respiration by interfering with proper electron transport from cytochrome b to cytochrome c1.

- It includes Mancozeb, Tebuconazole, Triazole, Chlorothalonil etc.
- Chlorothalonil is a chloronitrile fungicide that functions through multiple modes of action

### Conclusion:

Addressing the issue requires an integrated approach. Strategies such as reducing pesticide application, promoting Integrated Pest Management (IPM), restoring pollinator habitats, and adopting pollinator-friendly agricultural practices are essential. Regulatory frameworks should evaluate pesticides risks to non-Apis species, supported by research into safer pest control alternatives. Additionally, stricter regulations on pesticide use and research into alternative pest control methods can further protect these critical pollinators.

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# Sex Expression in Papaya (*Carica papaya* L.): Farmer Challenges and Sustainable Management Strategies

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Sex expression in papaya (*Carica papaya* L.) is governed by nascent sex chromosomes, leading to female, male, and hermaphrodite plants, with environmental stresses causing reversals that challenge yield optimization. Farmers face high costs from unidentified males, but molecular tools and cultural practices enable sustainable management.

## Sex Types and Genetic Mechanisms

Papaya (*Carica papaya* L.), a major tropical fruit crop, exhibits trioecious sex expression: females (XX, homogametic, round fruits), males (XY, staminate flowers only), and hermaphrodites (XYh, elongated fruits preferred commercially). Visual sex determination in papaya follows: hermaphrodites have five petals, ten anthers, and one ovary; females show five petals and a rounded ovary sans anthers. However, this delays identification until flowering (3-6 months), incurring costs from development of non-productive males. The sex locus on linkage group 1 spans ~8 Mb non-recombining regions—male-specific Y (MSY) and hermaphrodite-specific Yh (HSY)—with genes like gynoeceum suppression function (GSF) inhibiting carpels in males and stamen promotion function (SPF) promoting androecium.

Hormonal regulation involves ABA and auxin, alongside epigenetic and transcriptional controls during early floral differentiation. Intermediate forms (e.g., Types I-V per Storey, 1941) arise from disruptions.

## Environmental Influences on Sex Expression

Environmental cues profoundly alter hermaphrodite flower development, reducing fruit set. Carpeloidy transforms stamens into carpel-like structures, impairing pollination. High temperatures, water

stress, low night temperatures (~12°C), and nutrient scarcity trigger reversals: hermaphrodite-to-male under heat/water deficit; male-to-hermaphrodite under cool nights. Water stress amplifies secondary sexual dimorphism (SSD), with hermaphrodites showing faster growth but vulnerability. In India, variable climates exacerbate carpeloidy (stamens to carpels) and pentandry (stamen-ovary fusion).

## Challenges for Farmers

Early sex identification is impossible visually until 3-6 months, forcing overplanting (2-4 seedlings/hole) and rouging of males post-flowering—50% plants discarded, wasting inputs (water, fertilizers, pesticides). This inflates costs by 55% labour and reduces yields (females/herms ~100 fruits/tree/year).

Sex reversals disrupt ratios (ideal 1 male: 10-15 herm/females), especially in open fields like Haryana's heat-prone areas. Diseases (PaLCuV) confound typing, and low hermaphrodite preference in varieties like 'Maradol' limits markets.

Challenge	Impact on Yield/Cost	Regional Example (India)
Late Identification	50% males planted, rouging labour	₹20,000/ha extra inputs
Environmental Reversals	30-40% hermaphrodites-to-male shifts	Heat in Punjab/Haryana
Variable Ratios	Suboptimal pollination/fruit set	<70% hermaphrodites in fields

## Sustainable Management Strategies

Molecular markers (SCAR T12/W11, RAPD-OPs) predict sex at seedlings with 97-100% accuracy,



enabling single-planting and 55% cost savings. Random Amplified Polymorphic DNA (RAPD) and Sequence-Characterized Amplified Region (SCAR) markers revolutionized papaya sexing. RAPD, using 10-mer primers, detects male/hermaphrodite alleles rapidly via touchdown PCR (Td-PCR), achieving high accuracy. Loop-mediated isothermal amplification (LAMP) suits field use with minimal gear. Targeting papaya sex-linked regions, it distinguishes sexes at early growth, addressing dioecious challenges without labs. Eco-physiological phenotyping via reflectance indices (NDVI, PRI under drought) offers non-destructive sorting.

**Cultural practices:** Maintain 25-30°C day/11-16°C night; balance N (avoid scarcity); apply biostimulants or biochar to buffer stresses like waterlogging. Marker-assisted selection (MAS) and

transgenic targets GSF/SPF for hermaphrodite-biased lines. In sustainable systems, intercropping (e.g., papaya-onion) and precision irrigation optimize ratios while enhancing soil health.

Strategy	Tools/Practices	Benefits
Molecular Screening	SCAR/LAMP at 4-6 weeks	Early culling, +30% yield
Stress Mitigation	Temp control, biochar/N management	Reduce reversals 20-40%
Breeding	MAS for herm lines	Stable ratios long-term



## Blue Oyster Mushroom (*Pleurotus ostreatus*): An Engineering Approach to Nutrition, Moisture Management and Value Addition

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Blue oyster mushroom (*Pleurotus ostreatus*) is an economically and nutritionally important edible fungus known for its efficient utilization of lignocellulosic residues, high biological efficiency and adaptability to diverse agro-climatic conditions. From a soil and water engineering perspective, its growth is strongly influenced by substrate moisture content, porosity, aeration and water retention characteristics, analogous to soil–water–plant relationships. This article presents a technical overview of its nutritional value, cultivation requirements, substrate–moisture interactions and value-addition potential, highlighting its relevance for sustainable food systems and agri-based entrepreneurship.

### Introduction

Mushrooms are increasingly recognized as functional foods and sustainable agricultural commodities. Among cultivated species, *Pleurotus ostreatus* (blue oyster mushroom) is widely adopted due to its low production cost, rapid growth cycle and ability to convert agricultural residues into high-value protein-rich food (Chang & Miles, 2004).

Unlike conventional crops, mushroom production does not depend on soil as a growth medium; however, **substrate physical properties such as moisture retention, porosity and aeration play roles comparable to soil hydraulic characteristics**, making the system highly relevant for soil and water engineers (Beetz & Kustudia, 2004).

### Nutritional Composition and Health Benefits

Blue oyster mushroom possesses a balanced nutritional profile with high-quality protein, dietary fibre and essential micronutrients.

**Table 1. Proximate composition of *Pleurotus ostreatus* (fresh weight basis)**

Component	Value
Moisture (%)	88–90

Protein (g/100 g)	3.0–3.8
Carbohydrates (g/100 g)	4.0–5.5
Dietary fibre (g/100 g)	1.5–2.0
Fat (g/100 g)	0.3–0.5
Energy (kcal/100 g)	35–40

The mushroom is rich in potassium, phosphorus, iron and B-complex vitamins, contributing to cardiovascular health, glycemic regulation and immune enhancement (Ragunathan & Swaminathan, 2003).



Figure: Blue Oyster Mushroom (*Pleurotus ostreatus*)

### Agro-Climatic and Environmental Requirements

*Pleurotus ostreatus* is adaptable to a wide range of environmental conditions. While *blue oyster mushroom* cultivation is not yet as widespread or commercially produced as common oyster (*Pleurotus*) types, but it is grown in Odisha, Maharashtra, Andhra Pradesh, Karnataka, West Bengal, and Madhya Pradesh.

**Table 2. Optimal environmental parameters**

Parameter	Optimum range
Temperature	18–28 °C
Relative humidity	80–90%
Light	Diffused
CO <sub>2</sub> concentration	<1000 ppm
Ventilation	Essential during fruiting

High relative humidity is crucial for fruit body development, while excess CO<sub>2</sub> accumulation leads to elongated stipes and malformed caps (Stamets, 2000).

### Substrate, Moisture Dynamics and Soil–Water Analogies

Blue oyster mushroom is cultivated on lignocellulosic substrates such as paddy straw, wheat straw, maize stalks and sugarcane bagasse. These substrates function similarly to soil in terms of water holding capacity, pore space distribution and oxygen diffusion (Hudson, 1986).

Research indicates that substrate moisture content between **60–70% (wet basis)** is optimal for mycelial colonization and fruiting, while excess moisture causes anaerobic conditions and microbial contamination (Kumar & Ahlawat, 2012).

From a soil–water engineering viewpoint:

- Substrate porosity ↔ soil macro - and micropores
- Moisture retention ↔ field capacity
- Aeration ↔ soil oxygen diffusion rate

Such analogies aid in optimizing irrigation and humidity management strategies in mushroom production units (Agarwal & Chauhan, 2015).

### Cultivation Technology

The cultivation process involves:

1. Substrate chopping (3–5 cm)
2. Soaking and pasteurization
3. Spawning (2–3% w/w)
4. Incubation (10–15 days)
5. Fruiting and harvesting (20–30 days)

Biological efficiency of *Pleurotus ostreatus* ranges from 80–120%, depending on substrate quality, moisture control and environmental management (Royse, 2014).

### Post-Harvest Handling and Value Addition

Fresh mushrooms have a short shelf life (24–48 hrs at ambient conditions) due to high respiration rate and moisture content. Processing and value addition are essential for reducing post-harvest losses.

**Table 3. Value-added products and shelf life**

Product	Processing method	Shelf life
Dried mushroom	Hot air / solar drying	6–12 months
Mushroom powder	Drying + milling	6 months
Mushroom pickle	Blanching + oil	3–4 months
Mushroom chips	Frying / vacuum frying	2–3 months
Ready-to-cook mix	Dehydration	4–6 months

Drying kinetics, rehydration ratio and packaging permeability are key research areas for food and soil–water engineers (Singh *et al.*, 2011).

### Economic and Sustainability Aspects

Blue oyster mushroom cultivation:

- Requires low capital investment



- Has a short crop cycle (25–30 days)
- Utilizes agricultural waste efficiently
- Generates employment for SHGs and rural youth

The system contributes to nutritional security, water-use efficiency and circular bioeconomy, aligning with FAO's sustainable development goals (FAO, 2013).

### Conclusion

Blue oyster mushroom (*Pleurotus ostreatus*) represents a scientifically sound and economically viable enterprise. Its growth depends strongly on substrate moisture, porosity and aeration—parameters well understood in soil and water engineering. Integration of engineering principles with cultivation and processing can significantly enhance productivity, shelf life and profitability. The crop offers immense scope for interdisciplinary research and sustainable agri-food system development.

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## Tiny Terrors in the Coop: How Indigenous Traditional Knowledge (ITK) Are Outsmarting Poultry Red Mites

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In the quiet villages of Arunachal Pradesh, chickens are more than just poultry—they're part of the family. Although the term "backyard poultry farming" is relatively new among the scientific community. However, such practice of rearing indigenous chicken near human dwellings has been an integral part of tribal culture for generations. Nearly every household keeps 5 to 10 birds, clucking around the yard, laying eggs, and sometimes even sleeping near the doorstep. But living so close to our feathered friends has a dark side, one that's smaller than a grain of rice, yet causes outsized trouble. The **poultry red mite** (*Dermanyssus gallinae*), a blood-sucking nocturnal parasite hides during the day in cracks and corners, then come out at night to feast on the blood of sleeping chickens and when they run out of birds, they crawl onto humans. Causing, Intense itching, sleepless nights, and skin rashes, especially around the neck, arms, and waist.

### Broody Hens: The Perfect Victims

Red mites love stillness, which makes brooding hens, those sitting quietly for 21 days to hatch eggs becomes the perfect hosts. With the hen sitting motionless for days, mites multiply rapidly, draining her blood night after night. The hen becomes weak, anemic, and in some cases, may even die. Chicks and young birds are especially at risk. Infested birds become restless, start pecking their feathers, and eat less. Their egg production drops, and the few eggs they do lay may be stained with blood or mite droppings—not exactly something you'd want for breakfast. And it gets worse. Red mites are not just annoying but also dangerous. They carry diseases like Salmonella, Newcastle Disease, and avian influenza, making them a serious health threat in both backyard and commercial poultry farms.

### Humans Aren't Safe Either

Mites don't respect boundaries. Once they've infested a chicken coop, they often sneak into the house, hiding in bedding, clothes, or wooden furniture. People who handle poultry, especially

women, children, and farmers—report persistent itching, allergic reactions, and even breathing problems due to mite exposure. The mental toll includes anxiety, sleep loss, and in extreme cases, allergic asthma.

### When Modern Solutions Are Out of Reach

In cities, the solution might be a chemical spray or professional pest control. But in remote hills with poor roads, limited shops, and scarce vet services, that's not always an option. So how do tribal communities fight back? The answer lies in the wisdom of generations.

### Fern Power: Indigenous Traditional Knowledge (ITK) to the Rescue

In the absence of commercial veterinary support or chemical treatments—which are often hard to access in remote areas the tribal communities of Arunachal Pradesh have long relied on Indigenous Traditional Knowledge (ITK) to control red mite infestations. One such time-tested method is the use of fresh fern leaves in poultry shelters. These ferns, harvested from nearby forests, are spread in brooding nests and



perching areas. Their strong smell and natural compounds act as a natural mite repellent, disrupting the mite's life cycle and preventing infestation. Farmers replace the leaves every few days to maintain their effectiveness, especially during the brooding period. This practice is not only effective but also sustainable requiring no external inputs, no chemicals, and causing no harm to the birds or the environment. Moreover, the method reflects the community's deep ecological knowledge and their ability to adapt nature's resources for livestock care.



Pic.2 Fern leaves placed in brooding nest

### Final Thoughts: Small Bug, Big Problem—Simple Fix

Red mites may be tiny, but their impact is huge. From sick chickens to sleepless farmers, they disrupt lives and livelihoods. But thanks to traditional practices like the use of fresh fern leaves, and a deep-rooted connection between people and animals, these communities are proving that modern problems don't always need modern solutions.



Pic.1 Fern leaves



## **Methane – Ethylene Interactions in Enclosed Integrated Livestock–Crop Systems: Implications for Crop Physiology, Ripening, and Sustainability.**

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Integrated livestock–crop production systems constitute an important pillar of sustainable agriculture by promoting nutrient recycling and circular resource utilization. However, these systems frequently operate under semi-enclosed conditions that favor the accumulation of biologically active trace gases, particularly methane (CH<sub>4</sub>) and ethylene (C<sub>2</sub>H<sub>4</sub>). While the regulatory role of ethylene in plant development and fruit ripening is well established, the physiological relevance of methane in crop systems remains insufficiently explored.

Recent evidence suggests that methane may influence cellular redox balance, metal cofactor availability, and stress-related signaling pathways, thereby indirectly modulating ethylene biosynthesis and signal transduction. This review critically evaluates current knowledge on methane–ethylene interactions in integrated agroecosystems, focusing on biochemical mechanisms, molecular regulation, physiological responses, and postharvest implications.

We synthesize findings from controlled-environment experiments, greenhouse studies, and postharvest research to propose a conceptual framework describing how methane enhances ethylene-mediated responses. Furthermore, we discuss technological and management strategies aimed at mitigating adverse gas interactions. Improved understanding of atmospheric regulation in integrated systems is essential for optimizing crop productivity, quality, and long-term sustainability.

### **Introduction**

The increasing demand for environmentally responsible food production has accelerated the adoption of integrated livestock–crop systems worldwide. These systems are designed to enhance nutrient cycling, reduce external inputs, and improve farm-level resilience through functional integration of animal and plant production.

Despite their ecological advantages, integrated systems often create semi-enclosed environments characterized by altered atmospheric composition. Livestock respiration, manure decomposition, and enteric fermentation contribute substantially to methane emissions, while plant metabolism, microbial activity, and combustion sources generate ethylene. The simultaneous presence of these gases

distinguishes integrated agroecosystems from conventional open-field systems.

Ethylene plays a central role in regulating plant growth, senescence, abscission, and fruit ripening. Even trace concentrations can trigger significant physiological responses. In contrast, methane has traditionally been regarded as biologically inactive in plant systems. However, emerging studies indicate that methane may influence oxidative metabolism, stress tolerance, and signal transduction.

The potential interaction between methane and ethylene represents an underexplored dimension of crop physiology in enclosed agricultural environments. This review aims to consolidate current evidence, identify knowledge gaps, and provide a mechanistic perspective on methane–ethylene crosstalk in integrated systems.



## 2. Sources and Dynamics of Trace Gases in Integrated Agroecosystems

### Methane Production and Accumulation

Methane in livestock facilities originates primarily from enteric fermentation in ruminants and anaerobic decomposition of organic waste. In confined housing systems, methane concentrations may exceed ambient levels by several orders of magnitude, particularly under limited ventilation.

Seasonal variation, stocking density, feed composition, and manure management practices strongly influence methane emission rates. In integrated units where crop production is spatially connected to livestock housing, methane may diffuse into plant growth areas, resulting in chronic low-to-moderate exposure.

### Ethylene Generation in Crop Environments

Ethylene is produced endogenously by plant tissues and exogenously through combustion, microbial metabolism, and organic matter decomposition. Stress conditions, mechanical injury, and pathogen attack further enhance ethylene biosynthesis.

In greenhouse systems, inadequate ventilation can lead to continuous ethylene accumulation, particularly during fruit maturation and senescence phases. Co-occurrence with methane creates complex atmospheric conditions that may alter hormonal responses.

## 3. Ethylene Biosynthesis and Signal Transduction

Ethylene biosynthesis occurs through the Yang cycle, involving the conversion of methionine to S-adenosylmethionine and subsequently to 1-aminocyclopropane-1-carboxylic acid (ACC). The final step, catalyzed by ACC oxidase, requires molecular oxygen and ferrous iron as cofactors.

Ethylene perception is mediated by a family of membrane-associated receptors containing copper-binding domains. Upon ligand binding, downstream signaling cascades activate transcription factors, including ethylene response factors (ERFs), which

regulate ripening-, senescence-, and stress-related genes.

Regulation of this pathway is highly sensitive to cellular redox status, metal ion availability, and membrane integrity, making it susceptible to modulation by external environmental factors.

## 4. Emerging Evidence for Methane as a Physiological Modulator

### Methane and Redox Homeostasis

Recent investigations indicate that methane exposure may alter reactive oxygen species (ROS) metabolism and antioxidant enzyme activity. Moderate methane levels have been associated with enhanced activities of superoxide dismutase, catalase, and peroxidases, suggesting a role in redox regulation.

Changes in redox balance can influence ethylene biosynthesis by modifying ACC oxidase activity and stabilizing signaling intermediates.

### Effects on Metal Cofactor Availability

Iron and copper are essential for ethylene biosynthesis and perception. Methane-induced shifts in cellular redox state may affect the redox cycling of these metals, thereby modulating enzyme activity and receptor sensitivity.

Enhanced Fe<sup>2+</sup> availability may stimulate ACC oxidation, while altered copper coordination may influence receptor binding efficiency.

### Membrane and Structural Modifications

Exposure to hydrocarbon gases can affect membrane fluidity and permeability. Subtle changes in membrane properties may alter receptor conformation and signaling efficiency, contributing to amplified ethylene responses under mixed-gas conditions.

## 5. Physiological and Postharvest Consequences of Methane–Ethylene Interactions

### Growth and Senescence

Combined methane and ethylene exposure has been associated with accelerated chlorophyll degradation,



reduced photosynthetic efficiency, and earlier onset of senescence. These responses reflect intensified hormonal signaling and metabolic reprogramming.

### **Fruit Ripening and Quality Attributes**

Enhanced ethylene responsiveness promotes rapid softening, increased carotenoid accumulation, and elevated respiration rates. While nutritional attributes such as lycopene content may improve, excessive stimulation reduces textural integrity and marketable lifespan.

### **Postharvest Longevity**

Shortened shelf life represents a major economic constraint in integrated systems. Premature ripening increases susceptibility to mechanical damage, pathogen infection, and physiological disorders, leading to increased postharvest losses.

## **6. Conceptual Model of Methane–Ethylene Cross-Talk**

We propose a mechanistic framework in which methane indirectly amplifies ethylene signaling through three interconnected pathways:

1. Redox-mediated activation of ACC oxidase
2. Enhanced metal cofactor availability
3. Increased receptor sensitivity

These processes generate a positive feedback loop that accelerates ripening and senescence, resulting in a phenomenon referred to as premature ripening syndrome.

## **7. Management and Mitigation Strategies**

### **Biological Filtration**

Biological filtration using methanotrophic biofilters represents an environmentally sustainable approach for mitigating methane emissions in integrated livestock–crop production systems. These biofilters utilize specialized methane-oxidizing bacteria (methanotrophs) that metabolize methane as a carbon and energy source, converting it primarily into carbon dioxide and water. This biological oxidation process significantly reduces the concentration of

methane released into the atmosphere, thereby lowering the overall greenhouse gas footprint of agricultural operations. In addition to emission control, biofiltration enhances air quality within enclosed or semi-enclosed farming environments, creating a more favourable microclimate for crop growth and livestock welfare. Proper design of biofilter media, moisture regulation, nutrient availability, and microbial community management is essential to ensure long-term efficiency and stability of methane removal.

### **Ventilation Optimization**

Optimized ventilation systems play a critical role in regulating trace gas concentrations within integrated agricultural facilities. Dynamic ventilation regimes, tailored to specific crop developmental stages and livestock activity levels, enable precise control over internal atmospheric conditions. During early vegetative growth, moderate airflow maintains adequate oxygen supply while minimizing moisture loss, whereas increased ventilation during flowering, fruiting, or peak animal metabolic activity helps dissipate excess heat, humidity, methane, ethylene, and ammonia. Advanced ventilation strategies incorporating automated sensors, real-time monitoring, and adaptive control algorithms can further enhance system responsiveness. Such smart ventilation systems contribute to improved photosynthetic efficiency, reduced physiological stress, and enhanced productivity of crops, while simultaneously safeguarding animal health.

### **Chemical Regulation**

Chemical regulation through the application of ethylene antagonists provides an effective method for controlling excessive ethylene accumulation in enclosed agricultural systems. Compounds such as 1-methylcyclopropene (1-MCP) function by competitively binding to ethylene receptors in plant tissues, thereby inhibiting ethylene perception and downstream signaling pathways. This receptor blockade prevents premature senescence, abnormal ripening, leaf abscission, and stress-induced growth inhibition caused by elevated ethylene levels.



Strategic use of ethylene inhibitors is particularly valuable in high-density cropping systems, post-harvest storage facilities, and integrated environments where gaseous hormone buildup is common. However, dosage optimization, timing of application, and assessment of crop-specific sensitivity are essential to avoid unintended physiological disruptions.

### System-Level Design

System-level design is fundamental to minimizing gaseous and biological cross-contamination between livestock and crop production units. Physical separation through spatial zoning, partition walls, and compartmentalized housing reduces the direct transfer of methane, ethylene, ammonia, pathogens, and particulate matter. In parallel, controlled airflow pathways, established using pressure differentials, directional ventilation, and airlock chambers, ensure that contaminated air is efficiently exhausted away from sensitive crop zones. Integrated design approaches also incorporate buffer zones, filtration units, and biosecurity barriers to further enhance system integrity. By combining architectural planning with environmental engineering principles, system-level design supports sustainable operation, enhances biosecurity, and promotes long-term resilience of integrated farming systems.

### 8. Conclusions

Methane plays an active regulatory role in enclosed integrated farming systems by indirectly modulating ethylene biosynthesis and signaling. Through redox regulation, cofactor modulation, and membrane interactions, methane enhances hormonal sensitivity, leading to accelerated ripening and reduced postharvest longevity.

Recognition of atmospheric composition as a critical management variable is essential for improving productivity and sustainability in circular agriculture.

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## Purple Tomato: A Step Towards Revolution

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Rising nutritional insecurity and diet-related chronic diseases have increased the demand for nutrition-oriented crop improvement strategies. Tomato (*Solanum lycopersicum* L.) is widely consumed and rich in carotenoids and vitamins but lacks anthocyanins—bioactive flavonoids known for their antioxidant and health-promoting properties. Advances in conventional breeding and genetic engineering have enabled the development of anthocyanin-rich purple tomato, representing an important step toward biofortification of a staple horticultural crop. Purple tomatoes have been developed through introgression of anthocyanin-related loci from wild relatives and through transgenic expression of specific transcription factors, with genetically engineered lines showing anthocyanin accumulation in both peel and flesh. In addition to their distinctive pigmentation, purple tomatoes exhibit enhanced antioxidant capacity, extended shelf life, and reduced susceptibility to postharvest pathogens, contributing to lower postharvest losses. Evidence also suggests potential health benefits of anthocyanin intake, including reduced risk of cardiovascular and metabolic disorders. Recent regulatory approvals for the commercialization of genetically modified purple tomatoes for human consumption reflect a shift toward science-based governance of biotechnological innovations. Overall, purple tomato represents a consumer-focused innovation with significant implications for nutritional security, postharvest management, and future acceptance of genetically improved foods.

### 1. Introduction

The global agri-food system is undergoing a paradigm shift driven by rising nutritional insecurity, increasing prevalence of diet-related non-communicable diseases, and mounting pressure to produce more food with fewer resources. Fruits and vegetables have emerged as central components of this transition due to their role in delivering essential micronutrients, dietary fibre, and bioactive compounds that contribute to human health (Slavin & Lloyd, 2012). Recognizing their importance, the United Nations declared 2021 as the *International Year of Fruits and Vegetables*, emphasizing their role in achieving nutritional and food security worldwide (FAO, 2021).

Tomato (*Solanum lycopersicum* L.), one of the most widely consumed vegetables globally, holds a strategic position in human diets, have richness in carotenoids—particularly lycopene—along with vitamins, minerals, and phenolic compounds (Burton-Freeman & Reimers, 2011). Despite this, conventional red tomatoes lack anthocyanins, a class

of flavonoid pigments known for strong antioxidant, anti-inflammatory, and cardioprotective properties (Pojer *et al.*, 2013).

Advances in plant breeding and biotechnology have enabled the development of anthocyanin-rich purple tomatoes, offering a novel convergence of nutrition, crop improvement, and food innovation. Beyond their distinctive pigmentation, purple tomatoes represent a significant step toward biofortification strategies that prioritize consumer health benefits while addressing postharvest losses and sustainability challenges (Zhang *et al.*, 2013).

### 2. Purple Tomato: Development and Importance

The development of purple tomato is the result of sustained efforts to enrich tomato fruits with anthocyanins—flavonoid pigments naturally abundant in berries but largely absent in cultivated tomato fruits. Although the tomato genome possesses the structural genes required for anthocyanin biosynthesis, these genes remain transcriptionally inactive in most commercial varieties due to domestication-driven selection for red, lycopene-rich



fruits (Gonzali *et al.*, 2009; Sun *et al.*, 2020). Reactivating this dormant pathway has been achieved through both conventional breeding and modern biotechnological interventions.

Conventional breeding approaches exploited wild relatives of tomato which accumulate anthocyanins in fruit peel under specific light conditions (Bedinger *et al.*, 2011). The combined *Aft-atv* genetic background derived from wild tomato species confers peel-specific anthocyanin accumulation in conventionally bred purple tomato cultivars (Gonzali *et al.*, 2009). However, in these conventionally bred varieties, anthocyanin accumulation remains largely confined to the fruit peel, resulting in comparatively lower total anthocyanin content.

A major breakthrough was achieved through genetic engineering, where fruit-specific expression of transcription factors *Delila* and *Roseal*—derived from snapdragon (*Antirrhinum majus*)—successfully activated the anthocyanin biosynthetic pathway throughout both the peel and flesh of tomato fruits (Butelli *et al.*, 2008). This approach produced tomatoes with anthocyanin concentrations comparable to blueberries and blackberries, significantly enhancing antioxidant capacity (Butelli *et al.*, 2008). Subsequent studies demonstrated that these tomatoes exhibited delayed overripening, reduced susceptibility to postharvest pathogens, and nearly double the shelf life of conventional tomatoes, linking anthocyanin accumulation with improved oxidative stress management during ripening (Zhang *et al.*, 2013).

The importance of purple tomato extends beyond crop improvement to public health and food system resilience. Anthocyanins have been associated with reduced risk of cardiovascular diseases, metabolic disorders, certain cancers, and neurodegenerative conditions, supported by epidemiological and clinical evidence (Mattioli *et al.*, 2020).

**Table 1. Nutritional composition of red and purple tomatoes**

Analyte	Units	Non-GM Red tomato fruit	GM Purple tomato fruit
Moisture	g/100 g	94.72 ± 0.12	95.10 ± 0.12
Crude protein	g/100 g	0.64 ± 0.05	0.70 ± 0.09
Carbohydrates	g/100 g	3.06 ± 0.29	3.26 ± 0.27
Total sugars	g/100 g	2.72 ± 0.06	2.24 ± 0.17
Total fibre (AOAC)	g/100 g	1.10 ± 0.20	0.70 ± 0.10
Energy	kcal/100 g	18.4 ± 0.83	16.8 ± 0.77
Salt	g/100 g	<0.025 ± 0	<0.025 ± 0
Ascorbic acid (Vitamin C)	mg/100 g	6.86 ± 0.18	8.10 ± 0.86

(Martin & Butelli, 2024)

### 3. Threats and Opportunities

The emergence of purple tomato as a nutritionally enhanced crop presents a complex landscape of opportunities and challenges that extend across scientific, regulatory, socio-economic, and consumer domains.

One of the prime challenges confronting purple tomato, particularly GM variants is public perception of genetically engineered foods. Despite strong scientific consensus on the safety of approved GM crops, consumer scepticism persists, often fueled by misinformation, ethical concerns, and lack of long-term familiarity with such products (Qaim, 2020). Conventionally bred purple varieties often exhibit genotype × environment interactions affecting pigment accumulation, as anthocyanin synthesis is influenced by light intensity and temperature (Petric *et al.*, 2018). In genetically engineered lines, intellectual property constraints and seed access may



pose additional challenges for smallholder farmers in developing countries unless equitable licensing and public-sector involvement are ensured (Spielman & Smale, 2017).

Contrariwise, the growing global demand for functional foods and health-oriented diets has created a receptive market for nutrient-enriched produce (Granato *et al.*, 2020). Anthocyanin-rich tomatoes align well with this trend, offering visual novelty alongside scientifically validated health benefits. The enhanced shelf life and reduced postharvest losses reported in purple tomatoes provide additional economic incentives by improving supply chain efficiency and reducing food waste—an issue of particular relevance in tropical and developing regions where postharvest losses in tomatoes can reach 30–40% (FAO, 2019; Zhang *et al.*, 2013). Unlike earlier GM crops primarily designed for producer benefits such as pest resistance or herbicide tolerance, purple tomato delivers direct consumer advantages in terms of nutrition, quality, and storability (Martin & Butelli, 2024).

#### 4. Future Prospects

The future of purple tomato is closely linked with the global transition toward nutrition-focused, climate-resilient, and sustainable agriculture. Growing awareness of diet–health relationships is increasing demand for crops that provide added functional and nutritional benefits, positioning anthocyanin-rich purple tomato as a promising innovation (Granato *et al.*, 2020). Advances in metabolic engineering and genome-editing technologies such as CRISPR/Cas offer opportunities to further refine anthocyanin biosynthesis while maintaining yield and fruit quality (Gonzali & Perata, 2020). These approaches may also enable the development of non-transgenic purple tomatoes, potentially improving regulatory acceptance and consumer trust.

Purple tomato has potential to enhance dietary diversity and reduce micronutrient deficiencies, particularly in regions where tomato is a staple food (Burton-Freeman & Reimers, 2011). Its extended shelf life and resistance to postharvest pathogens may

help reduce food losses and improve supply chain stability under climate stress (Zhang *et al.*, 2013; FAO, 2019). Recent regulatory approvals in countries such as the United States and Australia reflect a shift toward science-based evaluation of biofortified crops, which could accelerate the adoption of similar innovations globally (USDA-APHIS, 2022; FSANZ, 2026).

#### 5. Conclusion

Purple tomato marks an important transition in modern horticulture, where crop improvement extends beyond yield to encompass nutrition, quality, and consumer well-being. By enriching a widely consumed vegetable with health-promoting anthocyanins, it exemplifies how scientific innovation can directly address nutritional security, postharvest losses, and evolving consumer expectations. While challenges related to regulation, perception, and adoption remain, the successful development and commercialization of purple tomato demonstrate its potential to reshape attitudes toward biofortified and genetically improved foods.

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# Volatile Organic Compound-Based Approaches for Plant Disease Detection

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Plants emit a diverse array of volatile organic compounds (VOCs) that serve as chemical signals reflecting their physiological state and responses to environmental stress. Pathogen infection disrupts normal plant metabolism, leading to characteristic changes in VOC emission profiles that can be exploited for early disease detection. This article highlights the role of VOCs as indicators of plant health and reviews major approaches for sampling and detecting disease-associated volatiles from infected plants. Common VOC sampling techniques, including static headspace sampling, purge-and-trap methods and solid-phase micro-extraction (SPME) are discussed alongside analytical and sensor-based detection platforms such as gas chromatography-mass spectrometry (GC-MS), proton transfer reaction-mass spectrometry (PTR-MS), selected ion flow tube-mass spectrometry (SIFT-MS), ion mobility spectrometry (IMS) and electronic nose systems. These technologies enable non-destructive, rapid and in some cases real-time monitoring of plant disease-related VOCs, often prior to the appearance of visible symptoms. By providing early and accurate detection, VOC-based detection methods hold strong potential for improving precision agriculture, reducing chemical inputs and supporting sustainable crop protection strategies.

## Introduction

Plants constantly release volatile organic compounds (VOCs) that act as chemical messages, helping them communicate stress and danger to their surroundings. When a plant is attacked by pathogens, its internal metabolism changes, leading to the emission of a distinct mix of VOCs. Nearby plants can “sense” these airborne signals and activate their own defense systems in advance. Because different stresses trigger different VOC blends, these emissions provide rich clues about a plant’s health. Infected plants and even the invading microorganisms themselves produce characteristic odour patterns that function like chemical fingerprints. By capturing and analysing these VOC signatures using tools ranging from advanced laboratory instruments to portable sensor-based devices, scientists can detect plant diseases early, often before visible symptoms appear. This non-destructive, real-time approach offers a promising alternative to traditional diagnostic methods and supports smarter, more sustainable crop protection practices.

## Volatile organic compounds (VOCs)

Volatile organic compounds (VOCs) are low-molecular weight chemicals with high vapour pressure and limited solubility in water that are released into the atmosphere by plants and other organisms. In plants, these compounds play a crucial role in indirect defense by functioning as airborne signals that help mitigate the effects of biotic stress. VOCs such as acetone and ethanol are emitted continuously and are involved in plant communication, competition, and defense strategies. Many VOCs are synthesized and stored in specialized tissues, including glands and ducts and are rapidly released following tissue damage. Once emitted, these compounds can deter herbivores and pathogens, attract natural enemies of pests and activate defense responses in neighbouring plants, even across species boundaries. Because plant VOCs are released as complex, dilute mixtures into the surrounding air, their effective detection and characterisation require sensitive analytical techniques with high resolution.



## Techniques for Sampling VOCs from Infected Plants

Several approaches are available for sampling volatile organic compounds (VOCs), including static headspace sampling, pre-concentration techniques and solid-phase micro-extraction (SPME). In the static headspace method, the sample is enclosed in a hermetically sealed vial and allowed to reach equilibrium so that VOCs accumulate in the air above the sample prior to analysis. Pre-concentration methods, commonly referred to as purge and trap techniques, involve passing an inert carrier gas over the sample to sweep volatile metabolites onto a trapping material, ensuring efficient transfer of VOCs to the detector. Among these methods, SPME is widely applied in volatile metabolite research. It is based on an adsorbent-coated fibre that selectively captures VOCs from the sample headspace. The trapped compounds are subsequently released by thermal desorption and introduced into the analytical system. Due to its simplicity, sensitivity and effectiveness in isolating odour-active compounds, SPME is regarded as one of the most reliable and versatile sampling methods for VOC analysis.

## Methods for detecting plant disease-related VOCs

Infected plants emit characteristic profiles of volatile organic compounds (VOCs) that can be exploited for disease detection. Several analytical approaches are widely employed for the detection and analysis of these VOCs, including Proton Transfer Reaction-Mass Spectrometry (PTR-MS), Selected Ion Flow Tube-Mass Spectrometry (SIFT-MS), Ion Mobility Spectrometry (IMS), Gas Chromatography-Mass Spectrometry (GC-MS) and electronic nose (E-nose) systems. Each technique is based on distinct operating principles and methodological workflows that enable the qualitative and quantitative assessment of VOCs released from pathogen-infected plant samples. The fundamental principles and methodologies associated with each of these techniques are outlined below.

## Proton Transfer Reaction-Mass Spectrometry (PTR-MS)

Proton transfer reaction-mass spectrometry (PTR-MS) is a rapid and highly sensitive technique used to monitor volatile organic compounds (VOCs) emitted from pathogen-infected plant samples. In this approach, whole plants or specific plant tissues are enclosed in a controlled chamber and the surrounding air containing plant-derived VOCs is continuously introduced into the instrument for analysis. A key advantage of PTR-MS is that it enables real-time VOC measurement without the need for complex sample preparation or solvent-based extraction. The technique operates on the principle of soft chemical ionisation, in which hydronium ions ( $H_3O^+$ ) transfer a proton to VOC molecules that possess a higher proton affinity than water. This process produces protonated VOC ions with minimal fragmentation, allowing reliable detection based on their mass-to-charge ratios. Variations in the composition and abundance of VOCs detected by PTR-MS reflect pathogen-induced metabolic changes in plants, highlighting its value as a non-destructive tool for early plant disease detection and monitoring.

## Selected Ion Flow Tube-Mass Spectrometry (SIFT-MS)

The operating principle of Selected Ion Flow Tube-Mass Spectrometry (SIFT-MS) is based on precisely controlled chemical reactions between selected reagent ions and volatile organic compounds (VOCs). In this technique, reagent ions such as  $H_3O^+$ ,  $NO^+$  and  $O_2^+$  are generated and introduced into a flow tube, where they interact with VOC molecules present in the sample air. These ion-molecule reactions produce distinctive product ions that are subsequently identified and measured according to their mass-to-charge ( $m/z$ ) ratios. Since the reaction pathways and rate constants are well established, SIFT-MS enables direct and accurate quantification of VOC concentrations. Variations in the composition and abundance of VOCs detected by this method reflect pathogen-induced metabolic changes in plants, underscoring the usefulness of SIFT-MS as



a non-destructive tool for early plant disease detection and monitoring.

### **Ion Mobility Spectrometry (IMS)**

Ion mobility spectrometry (IMS) is particularly attractive for plant disease studies due to its rapid response, portability and minimal requirement for sample preparation. The technique is capable of detecting changes in volatile organic compound (VOC) profiles within minutes, making it well suited for early, non-destructive diagnosis of plant infections under both laboratory and field conditions. IMS operates on the principle that ionised VOC molecules migrate through a drift tube under the influence of an electric field. VOCs are first ionised using a soft ionisation source, such as a radioactive source or corona discharge and the resulting ions pass through a drift region containing a neutral buffer gas. Because ions differ in size, shape and charge, they travel at different velocities, leading to their separation and detection as distinct signals. Pathogen-induced metabolic alterations in plants result in characteristic changes in VOC emission patterns, which can be recognized by IMS to distinguish infected plants from healthy ones.

### **Gas Chromatography-Mass Spectrometry (GC-MS)**

Gas chromatography-mass spectrometry (GC-MS) is a well-established and widely applied technique for analysing volatile organic compounds (VOCs) released from pathogen infected plant samples. The method is based on separating complex mixtures of volatiles according to their chemical properties, followed by accurate identification using mass spectral information. VOCs are commonly collected from the plant headspace through non-destructive approaches such as solid-phase microextraction (SPME) or dynamic headspace sampling, after which they are thermally released into the gas chromatograph. Within the GC system, individual compounds are separated in a capillary column and subsequently transferred to the mass spectrometer, where they are ionised, typically by electron impact, to produce characteristic fragment ions. These mass

spectra are compared with reference libraries or standards for compound identification, while quantification is achieved using internal or external standards. By comparing VOC profiles of healthy and infected plants, GC-MS enables the identification of disease-associated volatiles and the development of pathogen-specific chemical fingerprints, making it a benchmark tool for VOC-based plant disease detection and biomarker discovery.

### **Electronic Nose (E-NOSE)**

An electronic nose (E-nose) is a sensor-based technology designed for the rapid and non-destructive detection of volatile organic compounds (VOCs) emitted from infected plant samples. In this approach, healthy and diseased plants or plant tissues are placed in a sealed chamber and the headspace air containing plant-derived VOCs is passed over an array of gas sensors with varying sensitivities. Rather than identifying individual compounds, the sensor array records a collective response to the VOC mixture, generating a characteristic signal pattern. These sensor responses are subsequently analysed using pattern-recognition and statistical techniques, such as principal component analysis (PCA), linear discriminant analysis (LDA) or machine-learning algorithms to discriminate between healthy and infected plants.

The operating principle of an E-nose relies on changes in the electrical properties of sensors when VOC molecules interact with their surfaces. Sensors fabricated from materials such as metal oxides, conducting polymers or nanomaterials exhibit measurable changes in resistance or conductivity upon exposure to VOCs. Pathogen infection alters plant metabolic processes, leading to disease-specific VOC emission profiles that produce distinctive sensor response “fingerprints.” Although E-noses do not provide direct chemical identification of individual VOCs, their portability, low cost and ability to perform real-time analysis make them highly effective tools for rapid screening and early detection of plant diseases under both laboratory and field conditions.



## Conclusion

Volatile organic compound-based detection approaches offer a robust and emerging framework for the early detection of plant diseases by leveraging pathogen-induced chemical emissions. Recent developments in VOC sampling methodologies and analytical platforms, including both laboratory-based and portable technologies, have enhanced the accuracy, sensitivity and feasibility of disease monitoring. The identification of characteristic VOC emission patterns enables non-invasive detection at early stages of infection, facilitating timely disease management decisions. Despite existing challenges related to environmental influences, standardisation and large-scale deployment, continued technological refinement and integration with advanced data analysis tools are expected to improve reliability and field applicability. Collectively, VOC-based detection strategies represent a valuable contribution to precision agriculture and sustainable plant health management.

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## Robotics and Artificial Intelligence in Vegetable Production: Transforming Farming for a Smart and Sustainable Future

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Vegetable production plays a vital role in ensuring nutritional security, farm income and employment generation across the world. In India, vegetables occupy a prominent position within the horticulture sector, contributing significantly to agricultural diversification and dietary quality. However, vegetable farming is increasingly challenged by climate variability, labour shortages, rising production costs, pest outbreaks and declining resource use efficiency. In this context, robotics and artificial intelligence (AI) have emerged as transformative tools capable of reshaping vegetable production systems towards higher precision, resilience and sustainability.

Globally, agriculture is undergoing a technological transition from conventional mechanization to digital and intelligent farming systems. Robotics and AI form the backbone of this transition by enabling machines to perceive, analyze, decide and act autonomously or semi-autonomously in farm environments. While their adoption in cereal crops has progressed steadily, their application in vegetable production characterized by high crop diversity, delicate plant structures and intensive management represents a major technological breakthrough.

### Concept of Robotics and Artificial Intelligence in Agriculture:

Robotics in agriculture refers to the use of automated machines capable of performing tasks such as planting, weeding, spraying, harvesting and sorting with minimal human intervention. Artificial intelligence complements robotics by enabling machines to learn from data, recognize patterns and make intelligent decisions using algorithms such as machine learning, deep learning and computer vision.

### In vegetable production, AI-enabled robotic systems integrate:

- Sensors for data collection (optical, thermal, multispectral)
- Cameras for crop and pest recognition

- GPS and navigation systems
- Machine learning algorithms for decision-making
- Mechanical actuators for physical operations

The integration of these components allows precise crop management at plant or even leaf level, a feature particularly valuable for high-value vegetable crops.

### Global Status of Robotics and AI in Vegetable Production:

Advanced economies such as the United States, Japan, the Netherlands, Israel and China are at the forefront of deploying robotics and AI in vegetable farming. Labour-intensive operations like harvesting of tomato, lettuce, cucumber and capsicum have been the primary focus due to rising labour costs and workforce shortages.

### Globally, robotic vegetable farming is expanding in:

- Greenhouse and protected cultivation systems
- Large-scale commercial vegetable farms
- Urban and vertical farming units

For instance, AI-based harvesting robots capable of identifying ripe fruits using computer vision are increasingly used in greenhouse tomatoes and cucumbers (Bac *et al.*, 2013). Autonomous robots for



lettuce thinning and weeding have shown high efficiency and accuracy under field conditions (Slaughter *et al.*, 2008).

### Indian Scenario: Emerging Opportunities and Constraints:

In India, adoption of robotics and AI in vegetable production is still in a nascent stage, largely due to small landholdings, high initial investment and limited awareness. However, the growing emphasis on precision horticulture, protected cultivation and agri-startups is creating new opportunities. Indian agriculture faces acute labour shortages during peak vegetable harvesting seasons, particularly in peri-urban belts supplying fresh produce to cities. Robotics and AI can offer viable solutions by reducing labour dependency and improving timeliness of operations.

### Recent initiatives by Indian research institutions, startups and private companies are focusing on:

- AI-based crop monitoring apps
- Robotic weeders for vegetable crops
- Automated grading and sorting units
- Sensor-based irrigation and fertigation systems

Government programs such as Digital Agriculture Mission and Agri-Startup initiatives further support technological integration in horticulture.

### Role of AI and Robotics across Different Stages of Vegetable Production:

#### Land Preparation and Planting:

AI-enabled autonomous tractors and robotic planters are being developed to optimize land preparation and planting operations. These systems use GPS-based navigation and soil sensors to ensure uniform seed placement and optimal spacing.

#### Key advantages include:

- Precise planting depth and spacing
- Reduced seed wastage

- Improved crop uniformity
- Lower fuel and labour costs

Robotic transplanters are particularly useful for vegetable nurseries and transplanted crops such as tomato, brinjal, chilli and cabbage.

### Crop Monitoring and Growth Assessment:

Crop monitoring is one of the most successful applications of AI in vegetable farming. AI systems analyze data from drones, satellites and ground-based sensors to assess crop growth, stress and nutrient status.

#### AI-based crop monitoring enables:

- Early detection of nutrient deficiencies
- Identification of water stress zones
- Real-time growth tracking
- Yield prediction

Computer vision algorithms can detect subtle changes in leaf colour, canopy structure and plant vigour, allowing timely corrective measures (Liakos *et al.*, 2018).

### Precision Irrigation and Nutrient Management:

Water and nutrient management are critical in vegetable production due to shallow root systems and high nutrient demand. AI-based decision support systems integrate weather data, soil moisture sensors and crop growth models to optimize irrigation and fertigation schedules.

#### Benefits include:

- Reduced water use
- Enhanced nutrient use efficiency
- Prevention of nutrient leaching
- Improved crop quality

In protected cultivation, AI-controlled fertigation systems have significantly improved yield and



resource efficiency in tomato and cucumber crops (Jones *et al.*, 2017).

### **Weed Detection and Robotic Weeding:**

Weed management is labour-intensive and costly in vegetable production. AI-based robotic weeders use computer vision to distinguish crops from weeds and remove weeds mechanically or through precision spraying.

### **Robotic weeding systems offer:**

- Reduced herbicide use
- Lower environmental pollution
- Precise weed removal at early stages
- Suitability for organic vegetable farming

Field trials have shown that AI-guided robotic weeders can achieve more than 90% weed control efficiency in vegetable fields (Slaughter *et al.*, 2008).

### **Pest and Disease Detection:**

Early detection of pests and diseases is crucial for minimizing yield losses and pesticide use. AI-based systems analyze leaf images to identify pest infestations and disease symptoms with high accuracy.

### **AI-based pest and disease detection helps in:**

- Timely intervention
- Reduced pesticide sprays
- Site-specific pest management
- Improved food safety

Machine learning models have successfully detected diseases such as tomato leaf blight, powdery mildew and viral infections under both field and greenhouse conditions (Mohanty *et al.*, 2016).

### **Harvesting Robots in Vegetable Crops:**

Harvesting is one of the most challenging operations for automation due to variability in fruit size, shape and maturity. However, significant progress has been

made in robotic harvesting of vegetables such as tomato, cucumber, lettuce and capsicum.

### **AI-enabled harvesting robots use:**

- Vision systems to identify harvest-ready produce
- Robotic arms with gentle grippers
- Algorithms to determine optimal picking force

### **Harvesting robots reduce:**

- Labour dependency
- Harvest losses
- Post-harvest damage

Although field-scale adoption in India is limited, greenhouse vegetable production presents a promising entry point for harvesting robotics.

### **Post-Harvest Handling, Sorting and Grading:**

AI and robotics play an important role in post-harvest operations, ensuring quality and market value of vegetables. Automated sorting and grading systems use machine vision to classify vegetables based on size, colour, shape and defects.

### **Advantages include:**

- Uniform grading standards
- Faster processing
- Reduced human error
- Enhanced export quality

Such systems are already in use for tomatoes, onions and potatoes in advanced supply chains.

### **Robotics and AI in Protected and Vertical Vegetable Farming:**

Protected cultivation systems such as greenhouses, polyhouses and vertical farms offer ideal environments for deploying robotics and AI. Controlled conditions allow accurate data collection and automation.



**AI-driven protected cultivation enables:**

- Climate control optimization
- Automated planting and harvesting
- Real-time disease monitoring
- High productivity per unit area

Vertical farming units use AI to manage lighting, temperature, humidity and nutrient delivery, making year-round vegetable production possible even in urban areas (Benke and Tomkins, 2017).

**Economic and Environmental Implications:**

Robotics and AI have significant economic and environmental benefits in vegetable production.

**Economic benefits include:**

- Reduction in labour costs
- Improved yield stability
- Higher produce quality
- Better market competitiveness

**Environmental benefits include:**

- Reduced chemical input use
- Lower water consumption
- Decreased carbon footprint
- Enhanced sustainability

While initial investment remains high, long-term gains and declining technology costs are expected to improve affordability.

**Challenges in Adoption of Robotics and AI in Vegetable Production:**

Despite their potential, several challenges hinder widespread adoption are as follows:

- High initial cost of robotic systems
- Limited access for small and marginal farmers

- Lack of technical skills and training
- Poor digital infrastructure in rural areas
- Need for crop-specific customization

Addressing these challenges requires policy support, public-private partnerships and capacity building.

**Future Prospects and Way Forward:**

The future of vegetable production lies in smart, data-driven and automated systems. With advancements in AI algorithms, sensor technology and robotics, vegetable farming is expected to become more precise and resilient.

**Key strategies for accelerating adoption include:**

- Development of affordable robotic solutions
- Customization for Indian cropping systems
- Integration with farmer advisory services
- Strengthening agri-startup ecosystems
- Promoting AI literacy among farmers

In the coming decades, robotics and AI will not replace farmers but will empower them to make informed decisions, reduce drudgery and enhance productivity.

**Conclusion:**

Robotics and artificial intelligence represent a paradigm shift in vegetable production systems. By enabling precision management, reducing labour dependency and enhancing sustainability, these technologies offer practical solutions to the pressing challenges faced by vegetable farmers. While global adoption is advancing rapidly, India stands at a crucial juncture where targeted investments, policy support and farmer-centric innovations can unlock the true potential of robotics and AI in vegetable production. Embracing these technologies will be essential for ensuring future food and nutritional security in a climate-constrained world.



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## Effect of Hidden Battle Against Antibiotic Resistance in Global Aquaculture

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Aquaculture is the rapidly expanding food production sector and is crucial for satisfying increasing global protein needs, with fish output projected to double by 2030. Nonetheless, its growth is jeopardized by antimicrobial resistance (AMR), fueled by overuse and non-medical application of antibiotics. A significant percentage of antibiotics enter water ecosystems unchanged, encouraging the development of antibiotic-resistant bacteria and resistance genes. Within the One Health approach, antimicrobial resistance (AMR) impacts human health, aquatic species, ecosystems, and food safety. In the absence of intervention, the use of antimicrobials could rise considerably by 2030. Sustainable approaches such as biosecurity, vaccines, probiotics, enhanced monitoring, and international regulatory collaboration are crucial for guaranteeing the long-term viability of aquaculture and safeguarding public health

### Introduction

Aquaculture is the productive industrial activity that will play a crucial role in providing solutions to the millennium challenge. Fish and seafood consumption will increase by 27%, according to expectations for aquaculture for 2030, in which a doubling of fish production is expected. which aims to provide people with food and protect the Planet from degradation. which shows how fishing and aquaculture help with nutrition and food security, the responsible use of natural resources, and the growth of society, the economy, and the environment. Aquaculture is expanding faster than any other area of animal production. Antimicrobials are used in aquaculture mainly for prophylactic purposes and metaphylactic treatment. Antimicrobials are used in aquaculture mainly for prophylactic purposes and metaphylactic treatment. in there aren't any antibiotics made just for aquaculture, approved medicines mad Antibiotics made for other areas of veterinary medicine are used instead because there aren't any antibiotics made just for aquaculture. When these drugs are used too much in aquaculture, aquatic antimicrobial-resistant bacteria (AMRB) are chosen and end up in food

products that people are supposed to eat. When these drugs are used too much in aquaculture, aquatic antimicrobial-resistant bacteria (AMRB) are chosen and end up in food products that people are supposed to eat. Aquaculture, the farming of fish, shellfish, and other aquatic organisms, has become the world's fastest-growing food production sector, outpacing traditional fisheries to meet surging global protein demands. threatening not just aquatic health but also human well-being through contaminated food chains and environmental spread.



Figure:1 mechanism of antibiotic resistance, created by VectorMine

### 2. Principle of Hidden Battle Against Antibiotic Resistance

Antibiotic resistance is frequently referred to as a concealed struggle since it occurs subtly at the



microscopic scale, yet it significantly impacts human health, animal well-being, and environmental sustainability. The foundation of this concealed conflict is rooted in the ongoing evolutionary conflict between microbes and antimicrobial substances. Another key principle is genetic adaptability of bacteria. Bacteria can acquire resistance not only through mutations but also via horizontal gene transfers having resistance genes through plasmids, transposons, and bacteriophages. The environment plays a subtle yet critical role. Antibiotic residues in water, soil, and sediments often from hospitals, farms, and pharmaceutical waste act as low-level training grounds where bacteria gradually adapt. This environmental dimension makes antibiotic resistance a one health issue, linking human health, animal health.

### 3. Environmental Effects

Antibiotics, typically released unmetabolized at 70–90%, pollute water, sediments, and ecosystems through effluents, waste, and leftover feed. This creates ongoing selective pressure, encouraging antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs) that spread via horizontal gene transfer in aquatic microbiomes.

1. Aquatic ecosystems act as reservoirs of resistance, interrupting nutrient cycling, biodiversity, and microbial populations essential for ecosystem stability.
2. The interaction of pollutants (like microplastics) and climate change rising temperatures boost bacterial growth, the evolution of resistance, and the virulence of pathogens exacerbates their spread, particularly in tropical and subtropical regions including Asia and the Mediterranean.
3. Resistance spreads through water currents, wildlife, and runoff, turning natural habitats into channels for ecological and zoonotic transmission.

### 4. Cautious and Accountable Use of Antibiotics

Antibiotics must be utilized solely when required for treatment under the guidance of a veterinarian or

after a professional diagnosis. Routine preventive use, metaphylactic application in whole populations without disease verification, and particularly growth enhancement must be eradicated or strictly restricted. Essential antibiotics for human health, specifically fourth-generation cephalosporins, must be preserved and utilized exclusively as final alternatives. This principle directly addresses the underlying cause of resistance in aquaculture settings.

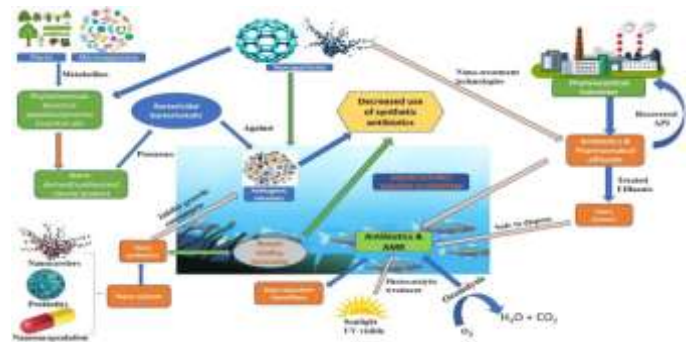


Figure:2 antibiotic resistance in aquaculture aquatic organisms

### 5. Prevention-First Approach (Biosecurity and Health Management)

Emphasize non-antibiotic strategies to avert disease outbreaks: stringent biosecurity measures, enhanced water quality management, ideal stocking densities, alleviation of stress, vaccination initiatives, and effective husbandry methods. This minimizes overall reliance on antibiotics and restricts selective pressure for resistance within agricultural systems.

### 6. Advocacy for Options Beyond Antibiotics

Proactively implement and expand the use of sustainable alternatives like probiotics (e.g. *Bacillus* spp., *Lactobacillus*), prebiotics, immunostimulants, bacteriophages, essential oils/monoterpenes, peptides, competitive exclusion microbes, and plant-derived antimicrobials. These methods boost immune response, lower pathogen levels, and break down biofilms without causing resistance.

### 7. Oversight, Observation, and Genetic Monitoring

Establish consistent, coordinated surveillance of antibiotic residues, antibiotic-resistant bacteria (ARB), and antibiotic resistance genes (ARGs) in



aquaculture facilities, adjacent waters, sediments, seafood items, and waste discharges. Employ sophisticated techniques such as whole-genome sequencing (WGS), metagenomics, and plasmidomics to identify resistance mechanisms and horizontal gene transfer. Information must contribute to national and international surveillance systems through One Health coordination.

### 8. Reductions in Environmental Dispersion and Lateral Gene Transfer

Reduce environmental pollution by enhancing wastewater treatment, cutting antibiotic waste (up to 75% can reach the environment), and controlling farm discharges to avoid the development of resistance reservoirs in aquatic ecosystems. Discuss the function of mobile genetic elements (plasmids, transposons) that facilitate the swift dissemination of antibiotic resistance genes among bacteria, including those affecting humans.

### 9. Regulatory Supervision, Enforcement, and International Cooperation

Create and implement national action strategies in accordance with global standards FAO, WHO, WOAHP This encompasses veterinary prescription mandates, prohibitions on non-therapeutic applications, residue thresholds in goods, and global collaboration particularly in high-production areas such as Asia exchange data, align standards, and enhance capabilities in resource-limited environments.

### 10. Wider Impacts Summarized from These Sources

- I. Public Health: Resistance genes/bacteria transmission through seafood intake or environmental contact; leads to worldwide AMR fatalities (>1.27 million annually).
- II. Aquatic/Animal Health: Disease incidents, unsuccessful treatments, large-scale fatalities (e.g., in shrimp/fish farms).
- III. Environmental: Antibiotic remnants remain in water/sediments, forming resistance hotspots";

as much as 75% of administered antibiotics are lost to the environment.

- IV. Economic/Food Security: Annual losses in the billions due to decreased yields; projected aquaculture expansion poses a risk of over 33% increase in antimicrobial usage by 2030 without action.
- V. Contributing Factors: Climate change (increased water temperatures encourage pathogens/resistance) exacerbates the problem

### 11. Environmental and Public Health Implications

The European Surveillance of Antimicrobial Consumption (ESAC) project collected data on antibiotic use for the period 1997–2001, and determined that the median national hospital antibiotic consumption in Europe was 2.1 DDD/1,000 inhabitants/day. Resistant bacteria and ARGs from farms spread via water currents, wildlife, and seafood trade, creating reservoirs in rivers, coastal zones, and even offshore environments. Seafood consumption and occupational exposure represent direct transmission routes to humans. Overlooked pathways include ornamental fish trade and integrated Agri-aquaculture systems.

### 12. Phage Therapy

Phage Therapy to Similar to other viruses, phages are unable to reproduce outside of their host. With rare exceptions, they often have a lipid bilayer acting as an envelope in addition to a protein coat (head). Bacteriophage's viruses that attack particular bacteria proved

targeted, environmentally friendly management without extensive microbiome alteration. Recent evaluations underscore increasing effectiveness against major pathogens (e.g., *Vibrio* in shrimp, *Aeromonas* in fish), exhibiting milder immune effects compared to antibiotics. Obstacles persist in formulation, delivery, and regulatory approval, yet phage cocktails are progressing toward commercial application. Bacteriophage's viruses that attack particular bacteria provide targeted, environmentally



friendly management without extensive microbiome alteration. Recent evaluations underscore increasing effectiveness against major pathogens (e.g., *Vibrio* in shrimp, *Aeromonas* in fish), exhibiting milder immune effects compared to antibiotics. Obstacles persist in formulation, delivery, and regulatory approval, yet phage cocktails are progressing toward commercial application.

**Figure: Phage Therapy Bacteriophage, created by BioRender.com.**

### Conclusion

Aquaculture plays a crucial role in future food and nutrition security; however, its quick growth has exacerbated the underlying risk of antimicrobial resistance (AMR). Inappropriate and excessive use of antibiotics results in the entry of resistant bacteria and genes into aquatic ecosystems, seafood, and eventually the human food supply. Pollution, climate change, and lax regulations contribute to the rapid spread of resistance. Addressing this issue necessitates a One Health strategy that emphasizes prevention, prudent antibiotic use, robust biosecurity, and sustainable options like probiotics and vaccines. Efficient monitoring, governance, and global collaboration are crucial to guarantee that aquaculture develops in a sustainable manner while safeguarding public health, ecosystems, and worldwide food security.

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# Quorum Sensing: A Smart Solution for Sustainable Aquaculture

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The rapid expansion of aquaculture has been increasingly challenged by disease outbreaks caused by bacterial and viral pathogens. Quorum sensing (QS), a population density-dependent bacterial communication system mediated by autoinducers such as acyl homoserine lactones (AHLs), plays a critical role in regulating virulence factors, including biofilm formation and toxin production. Targeting this communication pathway through quorum quenching (QQ) has emerged as a promising alternative to conventional antibiotic therapy. Beneficial bacteria such as *Bacillus* spp. produce QQ enzymes, notably AHL-lactonase encoded by the *aiiA* gene, which degrade AHL signaling molecules and attenuate pathogen virulence. Although QQ demonstrates significant potential for sustainable disease control in aquaculture, its practical application remains at an early stage. Critical challenges include optimizing dosage and treatment strategies, evaluating long-term ecological impacts, and integrating QQ approaches into comprehensive disease management frameworks. With further research and technological refinement, QQ-based strategies may offer an environmentally responsible and sustainable solution for disease control in aquaculture.

## 1. Introduction

This rapid development of aquaculture has been largely driven by the adoption of advanced and intensive farming methodologies. However, intensification practices in aquafarming have also introduced significant challenges. High stocking densities and increased production inputs often result in deteriorating water quality, elevated stress levels in cultured species, and greater susceptibility to infectious diseases (Boyd *et al.*, 2020). These factors compromise fish health and welfare, reduce productivity, and lead to substantial economic losses. Disease management therefore remains a major concern in modern aquaculture. Although antibiotics are commonly used to control bacterial infections, their prolonged and indiscriminate application raises concerns regarding antimicrobial resistance and environmental sustainability. As a result, considerable attention is being directed toward alternative and more sustainable approaches, including probiotics, vaccination, immunostimulants, strengthened biosecurity measures, and emerging microbial management strategies such as quorum sensing and quorum

quenching techniques. These innovative approaches offer promising prospects for disease control while reducing dependence on antibiotics. Quorum sensing was first identified in the late 1980s during studies on the bioluminescent properties of the Hawaiian bobtail squid *Euprymna scolopes*, whose light production is regulated by its symbiotic bacterium *Vibrio fischeri*. Subsequent investigations revealed that this phenomenon is mediated by a sophisticated cell-cell communication system in bacteria.

## 2. What is Quorum sensing?

Quorum sensing is a mechanism of bacterial communication that relies on the synthesis, release, detection, and coordinated response to small extracellular signalling molecules known as autoinducers (Fuqua and Winans, 1994; Fuqua and Greenberg, 2002; Waters and Bassler, 2005). As the bacterial population increases, the concentration of these signalling molecules accumulates in the surrounding environment. Once a threshold concentration is reached, the signals are detected by bacterial cells, triggering synchronized changes in gene expression. Through this density-dependent regulatory mechanism, bacteria are able to coordinate



their collective behavior in response to changes in population size and community structure. Quorum sensing thereby controls a wide range of group-based activities, including bioluminescence, production of virulence factors, biofilm formation (Fuqua *et al.*, 2001; Miller and Bassler, 2001), and the broader modulation of gene expression across the bacterial population.

### 3. Influence of Quorum Sensing on the Physical Properties of Biofloc

Biofloc consists of aggregated microbial communities, including phytoplankton, bacteria, and both living and dead particulate organic matter. Biofloc technology (BFT) operates by manipulating the carbon-to-nitrogen (C/N) ratio to transform toxic nitrogenous wastes into beneficial microbial protein, thereby enhancing water quality in zero-water exchange systems.

Within this system, quorum sensing plays a crucial regulatory role by controlling the secretion of extracellular polymeric substances (EPS), which are essential for microbial aggregation and floc formation (Shrout and Nerenberg, 2012; Lv *et al.*, 2014). EPS acts as a structural matrix that binds microbial cells and organic particles together. Consequently, EPS production significantly influences the physical characteristics of biofloc, including floc size, volume, and density (Si and Quan, 2017).

#### 3.1. Case study on the role of quorum sensing in biofloc

Fatimah *et al.* (2019) studied the role of quorum sensing (QS) in biofloc formation using the floc collected from a sequencing batch reactor operated with molasses as the carbon source and a 24-hour hydraulic retention time. They examined the effects of the QS inhibitor vanillin and AHL signal molecules (2  $\mu\text{M}$  OHL, 20  $\mu\text{M}$  HHL, and their combination) on biofloc characteristics and African catfish culture. The results showed that increasing vanillin concentration reduced biofloc formation, indicating that QS inhibition negatively affected floc development. In contrast, the combined AHL

treatment promoted larger floc particles, leading to higher floc volume and total suspended solids (TSS). Fish survival was highest in treatments with biofloc and AHLs, while the lowest survival was observed in clear water with AHLs. These findings suggest that QS plays an important role in improving biofloc structure and fish performance.

### 4. Influence of Quorum Sensing Biofilm Formation in Recirculatory Aquaculture System

Recirculating Aquaculture Systems (RAS) represent an advanced aquaculture technology in which water is continuously recycled and reused following mechanical and biological filtration to remove suspended solids and metabolic wastes. A central component of RAS is the biofilter, which supports nitrifying bacteria, including *Nitrosomonas* (ammonia-oxidizing bacteria) and *Nitrospira* and *Nitrobacter* (nitrite-oxidizing bacteria). These microorganisms are essential for the stepwise oxidation of toxic ammonia to nitrate, thereby maintaining water quality.

Within the biofilter medium, these microbial consortia develop as structured biofilms attached to the filter surface (King *et al.*, 2008; Suhr and Pedersen, 2010). The formation of this fixed-film community enhances the biological removal of ammonia and dissolved organic matter. Effective nitrification depends on coordinated interactions among consortium members, which regulate the expression of genes associated with nitrogen transformation processes. Quorum sensing signaling systems play a critical regulatory role in this context, governing biofilm development and dynamics, including microbial attachment, colonization, and detachment within biofilters. Therefore, quorum sensing is integral to biofilter stability, nitrification efficiency, and the overall functional performance of RAS.

### 5. What is Quorum Quenching?

Quorum quenching (QQ) has emerged as an innovative strategy of microbial antagonism that interferes with quorum sensing (QS)-mediated communication in pathogenic bacteria. By disrupting



QS-regulated virulence and pathogenicity, QQ is increasingly recognized as a promising and sustainable alternative to antibiotics for the biological control of aquatic pathogens (Defoirdt, 2013). Among the beneficial microorganisms employed in aquaculture, *Bacillus* spp., commonly isolated from environmental sources or the gastrointestinal tract of aquatic organisms are extensively utilized as antagonistic bacteria for disease management (Wang *et al.*, 2019). Under QS regulation, *Bacillus* spp. synthesizes a diverse array of bioactive secondary metabolites, including lipopeptides, polyketides, and other compounds exhibiting antibacterial, antiviral, and antitumor activities (Bareia *et al.*, 2018). Moreover, many *Bacillus* strains harbor the *aiiA* gene, which encodes the acyl homoserine lactonase enzyme AiiA (Dong *et al.*, 2000). This enzyme is one of the most well-characterized QQ enzymes and functions by specifically recognizing and degrading acyl homoserine lactone (AHL) signal molecules, thereby interrupting QS signaling pathways in pathogenic bacteria. Collectively, these characteristics underscore the significant role of *Bacillus* spp. in quorum sensing interference and sustainable disease control strategies in aquaculture systems.

### 5.1. Case study on quorum quenching in aquaculture

Chen *et al.* (2010) investigated the potential use of AHL-lactonase for controlling *Aeromonas hydrophila* infection in fish. The authors cloned and analyzed a 753-bp AHL lactonase gene (*aiiA* B546) from *Bacillus* spp. using specific primers (BT1 and BT2). The recombinant AiiA B546 enzyme was then expressed in *Pichia pastoris*, followed by fermentation, purification, and characterization of its enzymatic properties. The purified recombinant enzyme showed high specific activity, good stability across a wide range of pH and temperature conditions, strong resistance to protease degradation, and efficient hydrolysis of AHL signal molecules. To evaluate its protective effect, the enzyme was co-injected with *A. hydrophila* into common carp. Fish receiving both the enzyme and the pathogen exhibited significantly lower mortality ( $54.17 \pm$

$7.79\%$ ) and a delayed  $LT_{50}$  compared to fish injected with *A. hydrophila* alone ( $79.17 \pm 5.89\%$ ). These results indicate that AHL-lactonase effectively reduced bacterial virulence by disrupting quorum sensing. The study suggests that direct application of AHL-lactonase, either through injection or feed supplementation, may serve as a promising alternative to antibiotics for controlling *A. hydrophila* infections in aquaculture.

### 6. Challenges

The application of quorum quenching (QQ) in aquaculture requires comprehensive scientific evaluation. A major concern is the potential development of resistance mechanisms in pathogenic bacteria, such as *Bacillus thuringiensis* and *Pseudomonas fluorescens*, which may reflect broader issues related to plasmid-mediated antimicrobial resistance (Wang *et al.*, 2022). In addition, the long-term ecological impacts of QQ strategies must be carefully assessed, particularly their effects on non-target microbial communities and overall ecosystem health within aquaculture systems.

### 7. Conclusion

Quorum quenching represents a promising and environmentally sustainable alternative to conventional antibiotic-based disease control in aquaculture. While experimental evidence supports its efficacy in reducing pathogen virulence, further research is required to address resistance risks, ecological safety, and formulation challenges. With the development of potent and stabilized formulations and integration into comprehensive health management programs, QQ-based strategies have the potential to become a robust and sustainable approach for disease control in modern aquaculture systems.

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# From Millets to Milestones: Women-Led Agribusiness Startups Nourishing India’s Future

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*“Empowering women agripreneurs empowers families, food systems, and the future.”*

On International Women’s Day, the world pauses to celebrate women’s achievements and reflect on the road ahead toward equality. In India, one of the most transformative yet quietly unfolding revolutions is taking place far from corporate boardrooms—in farms, villages, Self-Help Groups, and small food processing units led by women.

Here, women are not just contributing labour to agriculture; they are building enterprises, creating brands, generating employment, and redefining food systems. Among the most promising examples of this change is the rise of women-led millet processing and healthy snack startups, where traditional grains are being transformed into modern, market-ready products.

This story is not only about business. It is about empowerment, nutrition, sustainability, leadership, and dignity.



## Women in Indian Agriculture: A Silent Strength

Indian women have always been at the heart of agriculture. They sow seeds, select grains, process harvests, preserve food, and manage household nutrition. Yet, for decades, their work remained:

1. Informal
2. Underpaid
3. Unrecognized

Women constitute nearly 60–70% of the agricultural workforce, but very few own land, control income, or participate in decision-making. International Women’s Day reminds us that true empowerment begins when women gain control over resources and livelihoods.

Agripreneurship—especially food processing and value addition—has emerged as a powerful pathway to achieve this transformation.

## Why Millets Are Central to the Women-Led Agribusiness Movement

Millets are not new to Indian kitchens. Ragi, jowar, bajra, foxtail millet, little millet, barnyard millet, and kodo millet were staples long before rice and wheat dominated diets. Women have preserved this knowledge for generations.

### What makes millets ideal for women-led startups is their unique combination of tradition and opportunity:

1. Climate resilience: Grow well in rainfed, drought-prone regions
2. Low input cost: Suitable for small and marginal farmers
3. High nutrition: Rich in fiber, iron, calcium, and micronutrients
4. Market demand: Increasing demand for gluten-free and diabetic-friendly foods

Millets are now repositioned as “smart foods”, and women entrepreneurs are playing a crucial role in this rebranding.



## From Grain to Brand: The Concept of Millet Processing Startups

A millet processing startup goes beyond farming. It involves:

1. Cleaning, grading, and milling raw millets
2. Roasting, puffing, or extruding grains
3. Preparing ready-to-cook and ready-to-eat products
4. Hygienic packaging and branding
5. Marketing through local, urban, and digital channels
6. For women, this model is especially suitable because it can be:
7. Home-based or cluster-based
8. Operated through SHGs or cooperatives
9. Scaled gradually with low financial risk

### Case Study: A Woman Entrepreneur Turning Millets into a Movement

#### Humble Beginnings

Smt. **Anita Devi** (name illustrative) hails from a small village in Karnataka's semi-arid belt. Her family cultivated ragi and foxtail millet on marginal land, but income from selling raw grain was barely sufficient. Like many rural women, Anita balanced farm work, household duties, and child care—with little financial independence.

Her journey changed when she joined a Self-Help Group (SHG) under the DAY-NRLM programme. Initially, the SHG was a savings platform. Gradually, it became a space for learning, confidence-building, and collective decision-making.

#### The Turning Point

In 2020, Anita attended a KVK-led training programme on millet value addition under the PMFME scheme. For the first time, she learned about:

1. Processing technologies
2. Food safety and hygiene
3. FSSAI registration
4. Market demand for millet-based foods

She realized that millets were no longer “coarse grains”—they were premium health products.

#### Birth of a Startup

With support from her SHG, Anita established a small processing unit in 2021. She invested in basic

machinery for cleaning, roasting, and milling, and registered her enterprise under Udyam and FSSAI. She named her brand “Shakti Millets”, reflecting strength, nutrition, and women's empowerment.

#### Products with a Purpose

Anita's product range was thoughtfully designed:

1. Ragi malt for children and pregnant women
2. Millet flour blends for diabetic and elderly consumers
3. Roasted millet snacks as healthy alternatives to fried foods
4. Ready-to-cook mixes for urban working families
5. Her branding focused on local sourcing, women-led production, and traditional nutrition.

#### Growth, Recognition, and Community Impact

Within two years:

The enterprise employed 15 women, all from nearby villages

Monthly turnover reached ₹3–4 lakh



#### Products entered urban organic stores and online platforms

Beyond numbers, Anita's success had a ripple effect:

1. Other women joined SHGs with confidence
2. Local farmers received better prices for millets
3. Nutrition awareness improved in the community
4. Anita evolved from a farm worker into a business owner, employer, and mentor.

#### Women-Led Millet Startups and International Women's Day

International Women's Day is not only about celebration—it is about creating ecosystems where women thrive. Women-led millet startups represent this ideal in action:

1. Women control income
2. Women lead enterprises
3. Women influence food choices
4. Women strengthen rural economies

These startups align perfectly with the global Women's Day message of equality through economic empowerment.

### Policy Support Fueling Women Agripreneurship

India's policy landscape increasingly recognizes the role of women entrepreneurs:

1. PMFME for food processing subsidies
2. DAY-NRLM for SHG mobilization
3. NABARD for finance and capacity building
4. KVKs and SAUs for technical support

When women receive training, credit, and market access, agriculture transforms from subsistence to enterprise-driven development.



### Women's Role in Millet Consumption and Economy

Several surveys and studies indicate the critical role women play in millet use and household decisions about nutrition:

Around 77% of rural millet consumption patterns are led by women, underlining their influence on both traditional diets and market demand for millet products.

### TRI – Transform Rural India –

This strengthens the case for women-led millet processing startups, since women are not only producers but also key decision-makers in dietary choices.

### Food Products from Millets (High Demand)

#### Traditional & Daily-Use Foods

- Millet flour (ragi, jowar, bajra, foxtail, little millet)
- Multigrain flour mixes
- Millet rice (cleaned, dehusked, polished)

- Millet dosa / idli batter (ready-to-cook)
- Millet papad & fryums
- Millet vermicelli (sevai)
- Millet roti & bhakri mixes

### Bakery & Snack Products (Very Profitable)

- Millet cookies & biscuits
- Millet cakes & muffins
- Millet rusks
- Millet namkeen & mixtures
- Millet chakli, mathri, khakhra
- Puffed millet snacks
- Roasted & flavored millet snacks

### Health & Wellness Products (Premium Market)

- Millet health drink powder
- Millet porridge / baby food
- Diabetic-friendly millet mixes
- Millet protein & energy bars
- Sprouted millet flour
- Millet-based weight-loss foods

### Sweet Products (Festive & Gift Market)

- Millet laddoos
- Millet halwa mix
- Millet chikki
- Millet laddoo premix
- Millet kheer mix

### Non-Food & Innovative Products

- Millet husk pillows (eco-friendly)
- Millet straw plates & packaging
- Millet bran for cattle feed
- Millet-based compost & manure
- Millet cosmetic scrubs (experimental/start-up level)

### Why Millet Processing Is Ideal for Women

1. Low investment and scalable
2. Suitable for SHG and cluster models
3. Strong government support
4. Rising health-conscious consumer demand

### Challenges on the Journey

Despite progress, women entrepreneurs continue to face:

1. Limited access to collateral and land ownership
2. Gaps in branding, packaging, and digital marketing



3. Social expectations and time constraints
4. Addressing these challenges requires mentorship, gender-sensitive finance, and policy handholding.

**Why Supporting Women Agripreneurs Matters**

Empowering women through agribusiness leads to:

1. Improved family nutrition
2. Higher household income
3. Reduced rural migration
4. Stronger, more resilient food systems
5. Investing in women agripreneurs is not charity—it is smart agricultural economics.

**Conclusion: When Women Lead, Agriculture Thrives**

Women-led millet startups symbolize a future where agriculture is inclusive, nutritious, sustainable, and profitable. On this International Women’s Day, their stories remind us that empowerment does not begin with slogans—it begins with opportunity, ownership, and trust.



# Biodegradable Seed Coatings: A Smart Ally for Small Farmers

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Across villages and farming communities, one question keeps coming up: how can farmers get more yield from the same land, with less risk and without harming the soil? Biodegradable, eco-friendly seed coatings are one practical answer. They start working before the crop even emerges, helping each seed survive, grow, and perform better, while also protecting the environment.

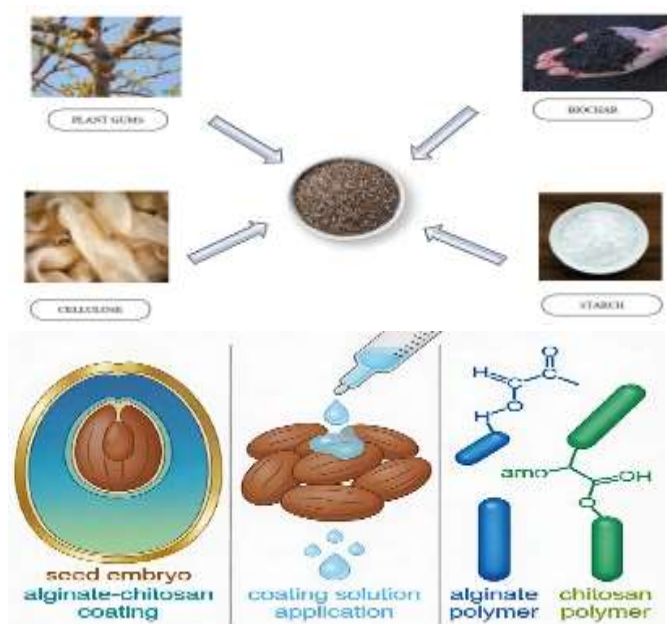
Instead of relying on heavy chemical dressings and plastic-like polymers, these coatings use natural materials that support the seed and then safely break down in the soil. For small and marginal farmers, this means better crop establishment, more stable harvests, and healthier land over the long term.

## What Exactly Is a Biodegradable Seed Coating?

Biodegradable seed coating is a thin, protective “jacket” around the seed. This jacket is made from natural, decomposable materials—such as starch, cellulose, plant gums, alginate, chitosan, silk proteins, plant fibres, or biochar—rather than synthetic plastics or petroleum-based polymers.

This coating:

- Holds gently onto the seed.
- Keeps the seed safe during handling and sowing.
- Creates a small, favourable micro-environment when the seed starts to absorb water and germinate.
- Gradually softens, releases its contents, and then decomposes in the soil.



Because the materials are biodegradable and bio-based, they do not leave behind microplastics or persistent chemical residues. Instead, they break down into harmless organic compounds that soil microorganisms can use.

## How Do These Coatings Help Seeds Grow?

The earliest days of a plant’s life are also the most delicate. A small shock at this stage—sudden dryness, a soil-borne disease, or a burst of heat—can kill the seedling before it properly establishes.

Biodegradable coatings are designed to support the seed through this critical window.

### 1. Better moisture management

Many natural polymers act like tiny sponges. They absorb water with the first rains or irrigation and release it slowly around the seed. Even a short dry spell, which might otherwise cause the seedling to die back, can be buffered by this local moisture reservoir. This is especially valuable in rainfed systems where rainfall is irregular.

### 2. Localized nutrition and growth support

The coating can carry small amounts of:

- Nutrients (N, P, K and micronutrients),
- Natural growth-promoting substances,
- Plant extracts that gently stimulate root development.

Because these are placed directly on the seed, they are delivered exactly where the young root system first grows. This targeted feeding can give seedlings a strong early push without requiring heavy fertilizer application across the entire field.

### 3. Protection through beneficial microbes

Biodegradable coatings can be “charged” with beneficial microorganisms such as plant growth-promoting bacteria and fungi. These microbes can:

- Fix nitrogen,
- Help solubilise phosphorus,
- Produce natural hormones that stimulate root growth,
- Compete with or suppress disease-causing organisms near the root zone.

The natural polymer matrix of the coating shelters these microbes until they reach the soil around the seed, improving their survival and effectiveness.

### 4. Shielding against pests and diseases

Coatings may also include plant-based biopesticides or microbial agents that discourage or kill harmful fungi and bacteria in the immediate vicinity of the seed. Because the treatment is highly localized, much smaller quantities are needed compared to broad spraying, which reduces cost and environmental load.

All these functions together usually translate into:

- Faster and more uniform germination,
- Stronger early root and shoot growth,
- More consistent plant stands across the field.

### Why Are Biodegradable Coatings Better for the Environment?

Conventional coatings often rely on synthetic polymers that do not readily break down. Over time, these materials accumulate as microplastics in the soil. They may interfere with soil structure, water movement, and the diversity of organisms that keep soil functioning well.

Biodegradable coatings avoid this issue. Once their job is done, soil microbes slowly digest them, turning them into:

- Carbon dioxide,
- Water,
- Small organic molecules that can become part of the soil organic matter.

If biochar or natural fibres are used, they can even contribute slightly to soil carbon and improve cation exchange and water-holding capacity over repeated use.

In simple terms, biodegradable coatings work with the soil, not against it. They fit naturally into regenerative and climate-smart agriculture approaches that value living soils, minimal pollution, and long-term productivity.



### Why Do Biodegradable Coatings Matter for Small Farmers?

For small and marginal farmers, each seed, each input, and each season feels high-stakes. Biodegradable seed coatings speak directly to those realities.

#### 1. More plants from the same seed

When farmers use home-saved seed or buy small packets of improved seed, wastage hurts. Poor germination leaves gaps, weak seedlings, and uneven crops. By improving both the percentage and speed of germination, biodegradable coatings help more of the sown seeds become healthy plants.

Benefits in the field include:

- Fewer empty patches,
- More uniform crops,
- Easier weed management, because a dense stand shades the soil faster.

Even a modest increase in final plant population can translate into noticeable yield gains, particularly where land is limited.

#### 2. Stronger seedlings, better chance of success

Seedlings emerging from coated seeds typically show:

- Faster early growth,
- Better root development,
- Greater tolerance to early droughts or brief stresses.

This early head start can make the difference between a crop that struggles all season and one that performs reliably. For farmers who cannot afford to re-sow or hire extra labour, this added security is highly valuable.

#### 3. More output from fewer inputs

Biodegradable coatings allow extremely targeted use of fertilizers and protective agents. Instead of broadcasting expensive inputs over the entire plot, farmers can:

- Place small doses right on the seed,
- Let the coating gradually release them where they are most needed.

This approach can:

- Lower the total amount of fertilizer or pesticide needed,
- Raise the efficiency of every kilogram applied,
- Reduce exposure risks for farmers and their families.

For households working with tight cash flows, this “do more with less” feature is one of the biggest attractions.

#### 4. Resilience in a changing climate

Rainfall variability, short dry spells, and soil fatigue affect smallholders first and hardest. Coatings that improve water availability around the seed and support early root expansion help seedlings survive under such uncertain conditions.

By combining moisture management, nutrition, and microbial support, biodegradable coatings reduce:

- The risk of stand failure,
- The chance of total crop loss from a bad start to the season,
- The need for emergency re-sowing, which is costly in both seed and labour.

This acts like an informal, low-cost insurance for farmers who otherwise have few buffers against climate shocks.

#### 5. Healthier soils, lower hidden costs

Over years, soils exposed to microplastics and heavy synthetic chemical loads may become less responsive and more difficult to manage. Farmers then have to spend more on:

- Organic amendments,
- Extra fertilizer,
- Corrective measures to reclaim structure and fertility.



By contrast, biodegradable coatings help maintain living, active soils and avoid this build-up of hidden problems. That reduction in future rehabilitation cost is an economic benefit, even though it is not always visible in a single-season budget.

### Economic Feasibility: Biodegradable vs Synthetic Coatings

From a farmer's point of view, the main question is simple: which option gives better returns for each rupee invested and each hour of labour?

#### Upfront costs

- **Synthetic coatings** use petroleum-based polymers and commercial chemical actives. These can become expensive where markets are volatile.
- **Biodegradable coatings** based on common starches, gums, fibres, or biochar can be relatively low-cost, especially if the raw materials are locally available. Some advanced bio-materials can be costlier, but basic farmer-friendly formulations need not be.

When coatings are applied by seed companies, the cost is folded into the price of coated seed. Once scaled, the gap between biodegradable and synthetic seed prices is often modest.

#### Returns over a season

Farmers care about:

- Yield per hectare,
- Quality of produce,
- Input costs (fertilizer, pesticides, labour),
- Risk of failure.

Biodegradable coatings can be more economical if they:

- Raise germination and yield enough to offset any extra seed cost,
- Allow farmers to cut back on some fertilizer or plant protection sprays,
- Reduce the need for re-sowing and extra labour.

In many smallholder situations, even a slight increase in yield coupled with small input savings can produce a clearly positive benefit–cost ratio.

#### Long-term view

Over several years, biodegradable coatings tend to look even more attractive economically because they:

- Avoid soil degradation linked to microplastics,
- Support soil biology, which reduces the need for corrective inputs,
- Help keep yields stable under variable conditions.

Synthetic coatings may control some pests effectively, but their long-term side-effects on soil and the environment can translate into extra hidden costs for the farmer later.

#### Practical Adoption on the Ground

For biodegradable seed coatings to really help farmers, a few practical needs must be addressed:

- **Access:** Farmers need easy access to coated seed—through cooperatives, seed companies, FPOs, or public programs.
- **Small packs:** Small, affordable packets fit the needs of marginal farmers better than large volumes.
- **Clear instructions:** Simple, local-language guidance on sowing depth, spacing, and storage of coated seeds helps ensure good results.
- **Storage care:** Because bio-coated seeds may contain living microbes or sensitive natural ingredients, they need to be stored dry, cool, and away from direct sunlight to maintain quality.

There is also potential for:

- Local entrepreneurs or SHGs to prepare simple biodegradable coatings using local materials,



- Farmer groups to experiment with low-cost recipes suited to their own crops and soils, under technical guidance.

### **A Practical Tool for Climate-Smart, Farmer-Friendly Agriculture**

Biodegradable, eco-friendly seed coatings bring several strands together: better germination, stronger seedlings, lower chemical load, healthier soils, and good economics over time. For small farmers, this technology is particularly powerful because it works at the seed level. It does not demand big machines, large landholdings, or high-risk investments.

Used wisely—along with good varieties, timely field operations, moisture-conserving practices, and integrated pest management—biodegradable seed coatings can become a quiet but important ally in building resilient, productive, and sustainable farming systems.

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# Tiny Fungus, Big Promise: How *Trichoderma*-Coated Seeds Help Farmers and the Planet

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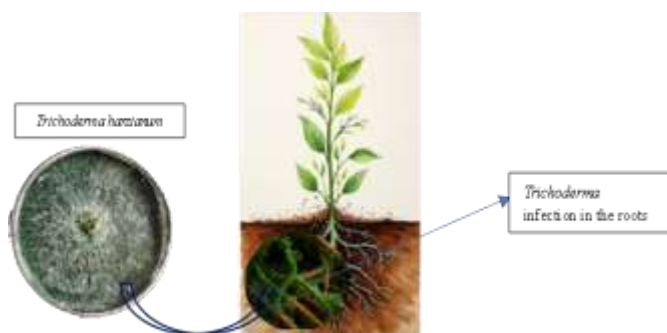
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Imagine a farmer standing at the edge of a field during the monsoon. The rains have been late, the soil looks tired, and there is not much money left in the budget for expensive pesticides. How can such a farmer grow enough food without breaking the bank or harming the earth?

The answer might be smaller than a grain of dust: a fungus called *Trichoderma*. When applied as a simple coating on seeds before planting, this microscopic helper can improve crop health, cut disease losses, and protect soil life – all for just a few rupees per kilogram of seed.

## What Is This Fungus, And Why Should Farmers Care?

*Trichoderma* is a genus of fungi that lives in soil all over the world. Unlike disease-causing moulds, the species that matter for farming – particularly *Trichoderma harzianum*, *T. viride*, *T. asperellum*, *T. virens*, and *T. atroviride* – actually partner with plants.



When a *Trichoderma* spore lands near a plant root, something remarkable happens. Instead of attacking the root, the fungus wraps around it like a protective sleeve, feeding on the plant's root sugars in exchange for several valuable services. It hunts down disease fungi, helps the plant sip more water and nutrients

from the soil, and even boosts the plant's natural defence system.

## How *Trichoderma* Protects Crops: Four Main Tricks

Scientists have identified at least four ways *Trichoderma* species save crops from disease:

### 1. Direct Attack on Harmful Fungi

Species like *T. harzianum* and *T. atroviride* are like tiny predators. They grow towards pathogenic fungi – such as *Fusarium*, *Rhizoctonia*, or *Pythium* – wrap around them, and break them apart using powerful enzymes. This process, called mycoparasitism, is particularly effective because the *Trichoderma* actively hunts its prey rather than just waiting for chemical diffusion.

### 2. Chemical Warfare

Many *Trichoderma* strains release natural antibiotics and volatile compounds that poison or slow down pathogenic fungi before they can infect the root. These chemicals create an invisible shield around the seedling.



### 3. Competition for Space and Food

*Trichoderma* grows very fast and colonises the soil immediately around the root, consuming sugars and minerals that disease fungi need. By occupying the "real estate" first, *Trichoderma* leaves pathogenic fungi with nowhere to establish themselves.

### 4. Boosting the Plant's Own Defence

Perhaps most cleverly, *Trichoderma harzianum* and *T. asperellum* can "train" the plant's immune system. The fungus releases signals that trigger the plant to produce defensive chemicals and proteins throughout its tissues, making the whole plant more resistant to infection – even on leaves and stems far from the root.

### The Practice: Simple Steps for Any Farmer

Seed coating is straightforward enough for a farmer to do at home with no special equipment. Here is what a farmer needs to do:

- **Make a mix:** Blend *Trichoderma* spores (from a commercial formulation or home culture) with water and a sticky agent – rice gruel, jaggery syrup, clay slurry, or even gum arabic works.
- **Coat the seeds:** Stir the seeds into the mixture until each one is lightly covered.
- **Dry in shade:** Spread them on a mat in the shade for a few hours until they are loose again.
- **Use soon:** Plant the coated seeds within a few days while the fungal spores are still alive and ready to work.



Agricultural universities and government extension offices in India now train farmers in this technique and often provide locally tested *Trichoderma* strains suited to rice, maize, pulses, vegetables and other crops.

### What Happens in the Field?

When a farmer uses *Trichoderma*-coated seeds, three changes often become visible over the season:

#### Healthier Seedlings

Fewer seedlings rot or die in the nursery or early field stage. The *Trichoderma* coating reduces the window of vulnerability – the first few weeks when young plants are most at risk from soil-borne diseases.

#### Better Growth and More Yield

Because the roots are healthier and the *Trichoderma* helps the plant absorb nutrients more efficiently, seedlings grow sturdier and faster. Research on rice, for example, shows grain yields can rise by 25–50% when seeds are treated with *Trichoderma* compared to untreated controls, depending on the farming method and soil condition. Similar gains have been documented in pulses, vegetables and maize.

#### Soil That Feels Alive

Farmers often report that soil treated with *Trichoderma* over seasons becomes darker, smells better (earthier), holds water longer, and supports more earthworms and other beneficial life. This happens because *Trichoderma* supports soil biology rather than disrupting it – unlike synthetic chemical treatments.

### Real Limits to Keep in Mind

*Trichoderma* is not a cure-all. Success depends on a few practical factors:

- **Fresh product:** The fungal spores must be alive and vigorous at the time of use. Old or poorly stored products do not work.



- **Right strain for the crop:** Different crops and climates may respond better to different *Trichoderma* species or strains, so local guidance matters.
- **Do not store coated seeds long-term:** Heat and humidity damage the fungal spores, so treated seeds are best used within days
- **Still need good farming:** *Trichoderma* is a tool, not a substitute for sanitation, crop rotation, and sensible timing – it works best alongside these practices.

### The Money Side: Why Farmers Adopt It

Here is where the economics get interesting. A *Trichoderma* product costs just ₹50–200 per kilogram, and a farmer uses only 5–10 grams per kilogram of seed – so the cost per seed treatment can be as low as ₹0.25–1 per kilogram.

#### In contrast:

- A chemical fungicide seed treatment can cost ₹5–10 per kg of seed and often needs repeated field sprays costing thousands of rupees per hectare.
- If *Trichoderma* increases yield by just 5–20% – which is often seen in field trials – that gain alone covers the seed treatment cost many times over.
- Add in the savings from fewer fungicide sprays and the reduced risk of complete crop loss due to disease, and the return on investment can be 10–30 times the cost of the product.

For smallholder farmers, this is not just a practical choice – it is a financial lifeline. A low-cost input that reduces risk, boosts yield potential, and cuts chemical costs can mean the difference between a year of profit and a year of loss.

### Looking Ahead

Researchers are continuously improving *Trichoderma* formulations. New work is exploring:

- Coatings made from biodegradable polymers that keep spores alive longer.
- Combinations of *Trichoderma* with other beneficial microbes for even stronger protection.
- Shelf-stable liquid and dry formulations that farmers can buy and use easily.

As climate change makes droughts, unpredictable rains and pest outbreaks more common, farming methods that build soil health and reduce chemical input become more valuable, not less.

### Conclusion: Nature's Insurance Policy at Seed Stage

*Trichoderma* seed coating represents an old idea updated with modern science: using nature's own solutions to solve farming problems. A microscopic fungus, applied to seed for a few rupees, can protect a crop throughout its life, improve soil for future seasons, and put more money in a farmer's pocket.

In a world where input costs keep rising and soils keep degrading, such low-cost, low-risk biology is no longer a luxury – it is becoming essential. From a farmer's perspective, treating seeds with *Trichoderma* is less like adopting a new trend and more like buying insurance: you spend a little now to avoid large losses later, and you grow a healthier farm at the same time.

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# Oyster Mushroom Cultivation: Demonstration of a Low-Cost Agri-Enterprise at KVK, Yachuli, Arunachal Pradesh

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Oyster mushroom (*Pleurotus spp.*) cultivation is a simple, low-investment, and short-duration enterprise with high nutritional and economic value. Krishi Vigyan Kendra (KVK), Yachuli has undertaken initiatives to demonstrate scientific oyster mushroom cultivation practices using locally available paddy straw. The present article outlines the cultivation methodology followed at KVK Yachuli, including technical requirements, stepwise production practices, and the nutritional and economic importance of oyster mushroom. The initiative highlights the potential of oyster mushroom cultivation as a sustainable agri-enterprise suitable for adoption under diverse agro-climatic conditions.

## Introduction

Mushroom cultivation is gaining importance as an alternative and supplementary income-generating activity in agriculture. Among different mushroom species, oyster mushroom (*Pleurotus spp.*) is widely preferred due to its ease of cultivation and adaptability to varied climatic conditions. To promote scientific cultivation practices and demonstrate its potential, Krishi Vigyan Kendra (KVK), Yachuli has undertaken oyster mushroom cultivation activities through practical demonstrations.

## Technical Requirements of Oyster Mushroom Cultivation

The basic technical and environmental requirements followed at KVK, Yachuli for oyster mushroom cultivation are presented in Table 1.

**Table 1: Technical Requirements of Oyster Mushroom Cultivation**

Particulars	Requirement
Mushroom species	Oyster mushroom ( <i>Pleurotus spp.</i> )
Substrate	Paddy straw
Temperature	20-30°C
Relative humidity	70-90%

Light	Diffused light
Incubation period	10-15 days
Cropping duration	25 days
Average yield	1.5 Kg/bag

## Cultivation Practices Followed at KVK, Yachuli

Oyster mushroom cultivation at KVK Yachuli is carried out using the polybag method. Paddy straw is chopped into small pieces, soaked in water, and subjected to hot water treatment to minimize contamination. After proper draining, the substrate is layered with quality oyster mushroom spawn in perforated polypropylene bag.

The filled bags are kept in a clean and dark room for incubation until complete mycelial growth. After incubation, the bags are shifted to a well-ventilated area where humidity is maintained through regular water spraying. Mushroom clusters develop within a few days and are harvested at the appropriate stage.

**Table 2: Stepwise Cultivation Process of Oyster Mushroom**

Stage	Activity
Substrate preparation	Chopping and soaking of paddy straw
Sterilization	Hot water treatment
Spawning	Layering of spawn with substrate



Incubation	Bags kept in dark, clean room
Fruiting	Moisture and ventilation maintained
Harvesting	Mushroom harvested in cluster



Fig.1: Chopping and soaking of paddy straw



Fig.2: Hot water treatment



Fig.3: Draining excess water



Fig.4: Oyster Spawn (Seeds)



Fig.5: Bag filling (Layering of spawn with substrate)



Fig.6: Lying and making holes to maintain humidity for fruiting



Fig.7: Harvesting within 25 days

### Nutrition and economic Importance

Oyster mushrooms are rich in protein, dietary fibre, B-complex vitamins, and essential minerals, while being low in fat and cholesterol. Regular consumption contributes to improved nutrition and health.

Economically, oyster mushroom cultivation requires minimal space and investment, offering quick returns within a short crop cycle. It has significant potential

as a supplementary income source and a small-scale agri-enterprise.

### Role of KVK, Yachuli, Arunachal Pradesh

KVK Yachuli plays a crucial role in demonstrating scientific oyster mushroom cultivation practices and creating awareness about its benefits. Through practical demonstrations, the KVK facilitates knowledge dissemination and skill development, encouraging adoption of this enterprise.



Fig.8: Group Photograph with Nichi Tain (SMS and RAWE Supervisor), Dr. Hage Munth (Senior Scientist and Head), and Dr. Nani Yampi (SMS Plant Protection) at KVK, Yachuli, Arunachal Pradesh, during Hands-on training on Oyster Mushroom cultivation

### Conclusion

Oyster mushroom cultivation represents a viable, sustainable, and low-cost agri-enterprise. The demonstration initiatives undertaken at KVK, Yachuli highlight the practicality and potential of this technology. With appropriate technical guidance and awareness, oyster mushroom cultivation can contribute to income enhancement and nutritional security.



# Successful Cultivation of Dalle Khursani: A GI-Tagged Chilli from Sikkim in Arunachal Pradesh

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**Dalle Khursani**, a GI-tagged chilli variety from Sikkim, is valued for its pungency, nutritional content, and market demand. A field study was conducted in Yachuli, Keyi Panyor, Arunachal Pradesh, on 1 acre of sandy loam soil, under rain-fed conditions, without chemical fertilizers or pesticides. The crop remained healthy throughout the growing season, with no pest or disease incidence observed. Each plant produced 500–600 g of fruits, sold at a market price of ₹80/kg. This study demonstrates that Dalle Khursani can be successfully cultivated under low-input conditions, providing high-quality produce and economic returns, while maintaining its GI authenticity.

## Introduction

Dalle Khursani, also called the Sikkimese chilli, is a high-value spice crop cultivated in the eastern Himalayan region. It has been awarded GI (Geographical Indication) status, ensuring the authenticity of its origin. While widely grown in Sikkim, limited studies exist on its adaptation to Arunachal Pradesh. This study evaluates the growth, yield, and economic potential of Dalle Khursani under low-input, rain-fed cultivation in Yachuli, Keyi Panyor.

## Materials and Methods

The materials used and cultivation practices followed during the study and summarized in Table 1.

**Table 1:** Cultivation details of Dalle Khursani under field condition in Yachuli, Arunachal Pradesh

5	Irrigation	Rain water only
6	Variety	Dalle Khursani (GI-tagged chilli of Sikkim)
7	Seed source	Local/Verified source
8	Fertilizer application	Not applied
9	Plant protection	Not applied
10	Crop management	Low-input traditional practice



Figure 1: Healthy Dalle Khursani plants with developing green fruits



Figure 2: Mature Dalle Khursani fruits ready for harvest



Figure 3: Harvested Dalle Khursani fruits, showing high yield and quality



Figure 4: Mature Dalle Khursani chilli harvested ready for sale

Sl. No	Particulars	Details
1	Location	Yachuli, Keyi Panyor, Arunachal Pradesh
2	Area under cultivation	1 acre
3	Soil type	Sandy loam
4	Climate	Rainfed condition

**Results**

The yield performance and field observations recorded during the cultivation period are presented in Table 2.

**Table 2: Yield and performance of Dalle Khursani**

Parameter	Observation
Plant health	Healthy, vigorous growth
Pest & disease incident	Not observed
Average yield (per plant)	500-600g/plant
Fruit quality	Uniform, pungent, marketable
Market price	Rs 80/Kg

**Discussion**

- Dalle Khursani is highly adaptable to Arunachal Pradesh conditions.
- Absence of pests or diseases highlights the crop’s resilience under natural, low-input management.
- High yield (500–600 g per plant) demonstrates that local farmers can cultivate this GI-tagged chilli profitably without chemical inputs.

- This RAWE-based study highlights practical cultivation techniques suitable for adoption in similar agro-climatic zones.

**Conclusion**

Dalle Khursani chilli can be successfully cultivated in Arunachal Pradesh using low-input, sustainable practices. The crop provides healthy, high-yield fruits with good market value, offering economic opportunities for farmers while maintaining its GI-tagged quality.

**Acknowledgments**

The authors sincerely thanks the local community of Yachuli, Keyi Panyor, and Dr. Sonbeer Chack (Assistant Professor) for guidance, support, and monitoring during cultivation.

**References**

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## National Pest Surveillance System (NPSS)

Priya Chouksey, Pramod Kumar Gupta, Siddharth Nayak, Deepti Dubey, Neha Sharma  
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The National Pest Surveillance System (NPSS) is a digital platform launched by the Government of India. The project is implemented by the Directorate of Plant Protection, Quarantine and Storage (DPPQ&S) in collaboration with the ICAR National Research Centre for Integrated Pest Management (ICAR-NCIPM), and technology partners including Wadhvani AI. NPSS includes a mobile application and a web portal together forming a nationwide system for pest surveillance, early detection, and expert advisory for pest and disease management in crops.

### Why NPSS was Needed

- Pest infestations and crop diseases remain among the major threats to agricultural production in India — historically causing significant losses in yield and farmer income.
- Traditional pest control often relies on pesticide retailers or unscientific methods, leading to overuse of chemicals, environmental harm, soil degradation, and health risks.
- With climate change, shifting cropping patterns, and evolving pest behaviour — there is a dire need for responsive, data-driven, and science-based pest management.
- Thus, NPSS aims to transform pest surveillance from reactive and fragmented to proactive, data-driven, and farmer-friendly.

### What NPSS Does — Features & Capabilities

- **AI/ML-based Pest Identification:** Farmers or field scouts can upload images of pests or affected crops using the NPSS mobile app. The system uses AI (including CNN-based models) to identify pests or diseases.
- **Expert Advisory & Recommendations:** Once pests are identified, agricultural experts generate and communicate pest-management advisories

tailored to the specific crop, pest, and local conditions.



- **Nationwide Surveillance & Data Collection:** NPSS builds a national database by collecting pest incidence data, images, and field reports across different agro-climatic zones. This helps in understanding pest trends, hotspots, and outbreak patterns at a macro level.
- **Support for Many Crops:** At launch, NPSS covers pests and diseases of 61 crops, with active monitoring for a subset of important crops including cotton, paddy (rice), wheat, maize, pulses, vegetables, horticultural crops, and more.
- **Accessible to Farmers Nationwide:** Through mobile phones (Android, iOS) and via a web



portal, NPSS aims to reach millions of farmers including small and marginal holdings.

- **Promoting Sustainable Pest Management & Integrated Pest Management (IPM):** NPSS encourages farmers to adopt scientific and sustainable pest control practices integrating biological, cultural, mechanical as well as chemical methods and thereby reduce overdependence on pesticides.

### How to Use the NPSS Mobile App (Step-by-Step)

#### Step 1: Download the App

- The NPSS mobile application can be downloaded from the **Google Play Store** (Android) and **Apple App Store** (iOS).
- Users may search for “NPSS” in the app store or use the official Play Store link.

#### Step 2: Install and Open

- Install the application on the smartphone.
- Open the app and follow the on-screen instructions.

#### Step 3: Login / Registration

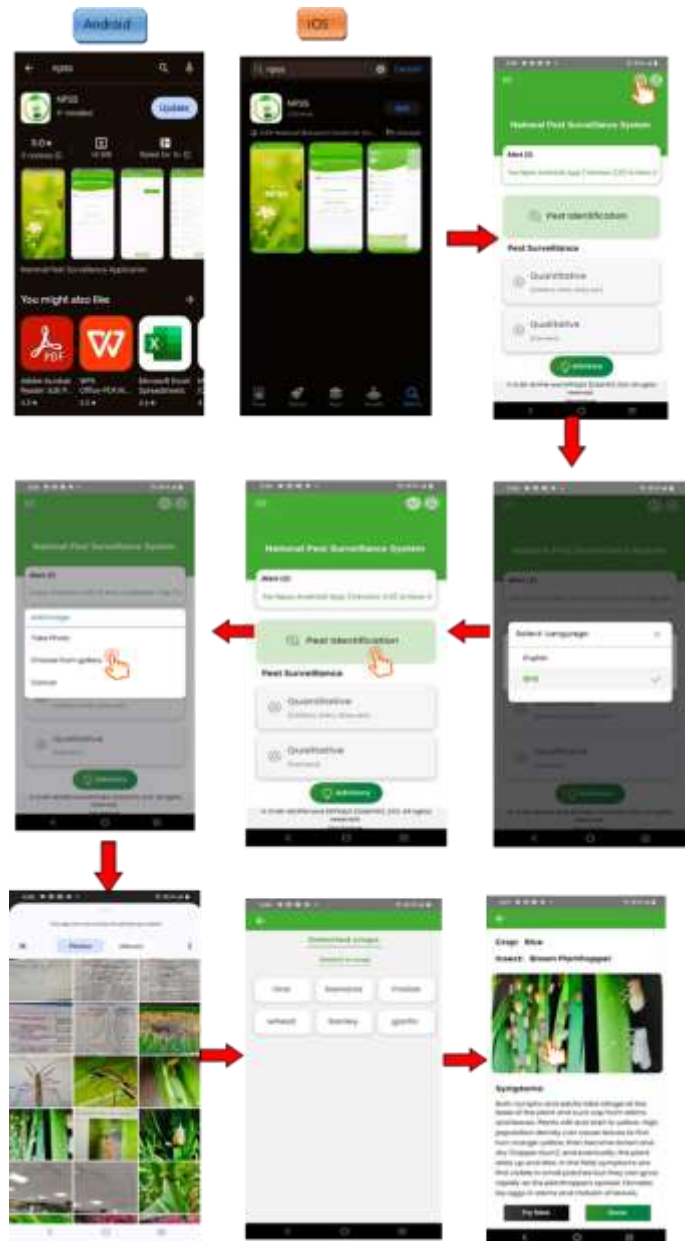
- New users may complete registration as guided in the app.

#### Step 4: Upload Pest or Crop Image

- Capture or upload a clear image of the affected crop or pest.
- Ensure proper lighting and visible symptoms for accurate identification.

#### Step 5: Receive Advisory

- The system analyzes the image using AI tools.
- Pest identification and management recommendations are provided through the app



#### Expected Benefits

- **Timely and Accurate Pest Diagnosis & Management:** Reduces delay in identifying pest issues, enabling early intervention before major damage.
- **Reduced Crop Losses & Higher Productivity:** By controlling pests effectively and timely, crop yield losses due to pests/diseases can be minimized protecting farmer income.



- **Lower Dependence on Pesticide Retailers:** Farmers get direct, science-backed advice rather than relying on informal pesticide sellers reducing misuse of chemicals.
- **Sustainability & Environmental Health:** Promoting IPM helps decrease pesticide overuse, preserving soil, water, biodiversity, reducing chemical residues and health risks.
- **Data-Driven National Pest Management:** The aggregated data can help policymakers, researchers, and extension agencies anticipate outbreaks, formulate better strategies, target interventions, and strengthen food security.

### Implementation — Progress & Scope

- The app and portal were officially launched on 15 August 2024 by the Ministry.
- Early roll-out is underway; as of mid-2025, the user base was limited (~ 30,000 users including farmers and extension workers) but with plans to expand to cover ~146 million farmers eventually across the country.
- The system already allows farmers to report pest incidences via image uploads, and experts have issued pest-management advisories based on these data.

### Partners Working for the Development of NPSS

The development and successful implementation of the **National Pest Surveillance System (NPSS)** is the result of coordinated efforts among national institutions and technology partners, as outlined below:

1. **Directorate of Plant Protection, Quarantine and Storage (DPPQ&S) and Central Integrated Pest Management Centres (CIPMCs)**  
Responsible for overall coordination,

implementation, and field-level pest surveillance activities across the country.

2. **ICAR – National Research Centre for Integrated Pest Management (ICAR-NCIPM), New Delhi**  
Provides scientific expertise, pest diagnostics, Integrated Pest Management (IPM) strategies, and validation of pest advisories.
3. **ICAR – Indian Agricultural Statistics Research Institute (ICAR-IASRI), New Delhi**  
Supports data analytics, statistical modeling, database management, and decision-support systems for pest surveillance.
4. **Private IT and Technology Partners (Plantix and Wadhvani AI)**  
Contribute advanced digital solutions, including AI/ML-based image recognition, mobile application development, and data processing platforms.

### What NPSS Means for a Farmer in Madhya Pradesh (or Your Area)

NPSS could matter locally:

- You could use your Smartphone (if available) to upload images of pests or crop damage and get expert recommendations without relying solely on local pesticide vendors.
- For crops like maize, wheat, pulses, or horticultural crops common in your region: NPSS can help detect early pest/disease threats, and suggest Integrated Pest Management (IPM) which might help reduce costs and environmental impact.
- Even if connectivity is limited, NPSS's national data-backed advisories could help local agriculture extension agencies plan timely interventions for your region improving overall resilience against pest outbreaks.



Given common crops in Madhya Pradesh especially wheat, maize, soybean, pulses, sugarcane, and maybe rice (depending on area), here's how NPSS could serve you:

- If you grow wheat, maize, soybean, or sugarcane these are among the 15 major crops so NPSS will likely support full surveillance/advisory for pests/diseases on these.
- If you grow rice (paddy) also covered under NPSS. Helps in identifying typical pests/diseases and getting advisories.
- If you grow pulses or other less common crops (or traditional local crops) NPSS may still help via the image-based pest identification module (since 61 crops are included). But full regular surveillance or expert advisory may not yet be guaranteed.
- If you are cultivating horticulture/fruit/vegetable crops (brinjal, tomato, etc.) and if these are supported in your state NPSS can be useful (though suitability depends on local availability of surveillance and advisory support).

### **What a farmer in MP should check before using NPSS for your crops**

- Confirm whether your crop is listed among the "15 major crops" under active surveillance/advisory. That gives better chance of timely expert advice.
- If you are growing a different crop (e.g. pulses, millets, oilseeds, local vegetables), you can still

use NPSS's image-based pest detection but the advisory might be limited.

- Make sure to upload clear images of damaged plants or pests good images help AI identification and expert verification.
- Even with NPSS, keep local state agriculture / extension contacts active for follow-up, ground-level advice and context-based pest management.

### **Conclusion**

The National Pest Surveillance System (NPSS) represents a crucial step toward modernizing Indian agriculture leveraging Artificial Intelligence, machine learning, and nationwide digital reach to transform pest management from reactive to proactive, scientific, and sustainable. For farmers across India including those in states like Madhya Pradesh NPSS offers the promise of early pest detection, expert guidance, lowered pesticide dependence, better yields, and healthier ecosystems.

The success of NPSS will depend on widespread adoption, digital access, consistent data reporting, and effective follow-up support on the ground. If these challenges are addressed, NPSS could reshape how India fights crop pests and diseases making agriculture more secure, sustainable, and farmer-friendly.

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# Application of AI in Livestock Management

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Artificial intelligence (AI) is emerging as a transformative technology in livestock and dairy management, enabling precision, automation, and data-driven decision-making across the production chain. This article reviews the major applications of AI in livestock systems, including animal health monitoring, behaviour and welfare assessment, precision nutrition, reproductive management, and yield optimization, along with its role in dairy processing and product quality control. AI techniques such as machine learning, deep learning, computer vision, and predictive analytics are increasingly integrated with IoT sensors, wearable devices, and smart imaging systems to generate real-time insights and support early intervention strategies. These technologies improve operational efficiency, enhance animal welfare, reduce resource wastage, and support sustainable farming practices. The article also highlights emerging frameworks such as edge computing and explainable AI that improve on-farm deploy ability and model transparency. Despite significant benefits, challenges related to data quality, infrastructure cost, technical expertise, and ethical considerations remain barriers to widespread adoption. Overall, AI-driven systems demonstrate strong potential to modernize livestock and dairy sectors by enabling intelligent, scalable, and welfare-oriented farm management.

## 1. Introduction

Livestock farming plays a critical role in food security, rural income, and agricultural sustainability. Traditional livestock management depends heavily on manual observation and experience, which may lead to delayed disease detection, inefficient feeding, and inconsistent productivity. Artificial Intelligence introduces automated monitoring, predictive analytics, and smart decision support systems that enhance productivity and animal welfare. Artificial intelligence (AI) is emerging as a critical enabling technology that requires rapid adoption in the livestock sector to improve productivity, efficiency, and decision-making. AI-based systems offer significant advantages across multiple operational areas, including animal monitoring, growth optimization, disease and pest management, biosecurity risk control, and overall farm management. By integrating AI with sensing and data acquisition technologies, livestock farms can continuously collect and analyse large volumes of data to generate actionable insights. These insights support accurate forecasting, improved production

planning, and better understanding of market and consumer behaviour, such as purchasing patterns and demand trends. Automation driven by AI further reduces manual intervention, lowers operational costs, and enhances the quality of livestock products such as milk, meat, and eggs, although initial investment requirements remain a barrier for many farms (Patel et al., 2022).

The concept of smart farming has evolved with the development of networked sensors, automation systems, and remote monitoring platforms. Smart farms utilize interconnected devices and digital infrastructure to monitor environmental parameters and livestock conditions without time and location constraints, enabling farmers to supervise operations through computers or smartphones. This paradigm has expanded into smart livestock farming, which emphasizes end-to-end data collection, analysis, and information sharing across the entire value chain from animal production and growth to distribution and consumption. Such a data-driven ecosystem supports evidence-based decision-making and creates additional operational and economic value.



However, despite technological progress, practical challenges remain in large-scale data acquisition, data quality, and the implementation of intelligent analytics, which limit adoption among many livestock producers.

Recent advances in deep learning based computer vision have strengthened intelligent monitoring capabilities in livestock barns. Modern object detection models are increasingly used to identify animal conditions, lesions, and abnormal or inactive behaviour using CCTV imagery. Traditional real-time detection systems have commonly relied on the YOLO (You Only Look Once) family of models, such as YOLOv5 and YOLOv8, which employ Non-Maximum Suppression (NMS) as a post-processing step to remove redundant bounding boxes based on Intersection over Union (IoU). While effective, NMS introduces additional computational overhead and may reduce detection efficiency under complex conditions. Transformer-based detection models such as Real-Time Detection Transformer (RT-DETR) provide an alternative approach by eliminating the need for NMS and improving detection accuracy and speed. RT-DETR reduces computational cost through optimized query initialization and is well suited for real-time barn monitoring using large-scale CCTV datasets. Comparative evaluations indicate that RT-DETR can outperform YOLO-based methods in detecting cattle lesions and abnormal maintenance behaviours, thereby improving monitoring reliability, operational efficiency, and overall livestock farm productivity (Shin et al., 2025).

## 2. AI for Animal Health Monitoring

With the rapid advancement of artificial intelligence technologies, significant progress has been achieved in the field of animal health monitoring. AI-driven systems are increasingly being used to support veterinarians and livestock managers in the early detection, diagnosis, and management of diseases. Advanced algorithms can analyse medical images,

sensor data, and clinical records to identify disease patterns and classify health conditions with higher accuracy and speed than conventional methods. Computer vision models assist in detecting visible symptoms such as lesions, lameness, and body condition changes, while signal- and sound-based AI models help recognize respiratory disorders and abnormal behavioural patterns. These capabilities enable continuous, non-invasive, and automated health surveillance across large animal populations (Ali and Al-Zubi, 2023).

AI-based predictive analytics further strengthens animal health monitoring by integrating multiple data sources, including electronic health records, physiological sensor data, and genetic information. By identifying hidden trends and risk indicators, these models can forecast potential disease outbreaks and health deterioration before clinical symptoms become severe. Remote monitoring platforms connected through IoT networks allow real-time tracking of vital parameters such as activity, temperature, rumination, and heart rate, enabling timely alerts and rapid intervention (Semenov et al., 2025). This supports a shift from reactive treatment to preventive and individualized healthcare strategies in both livestock and companion animals.

Current evidence from research studies and clinical deployments shows that AI-assisted analysis accelerates treatment discovery, improves diagnostic consistency, and enhances understanding of animal health dynamics. However, effective implementation of AI in animal health monitoring also requires attention to data privacy, ethical use, model transparency, and appropriate regulatory frameworks. Addressing these factors is essential to ensure that AI systems are reliable, safe, and practically useful for large-scale animal healthcare applications (Fig. 1).





Fig. 1 AI health monitoring of cattle

### 3. AI in Precision Feeding and Nutrition

The role of artificial intelligence (AI) in precision nutrition is expanding rapidly, supporting more accurate, data-driven approaches to diet planning, disease prevention, and performance optimization. AI-based precision nutrition systems analyse large and diverse datasets including feed composition, intake behaviour, physiological responses, and health indicators to generate individualized nutrition strategies. Recent literature shows a strong growth in AI-driven precision nutrition research, particularly after 2020, with a major focus on diet-related disorders, metabolic efficiency, and preventive health management. These systems are designed not only to improve productivity and health outcomes but also to support long-term sustainability through optimized resource utilization (Wu et al., 2025).

Across current studies, AI applications in precision nutrition commonly include predictive modelling, recommendation systems, pattern recognition, and natural language processing–assisted knowledge extraction. Machine learning and deep learning models are used to relate nutritional inputs with outcomes such as growth rate, milk yield, metabolic disorders, and cardiovascular or glycaemic risks (in both human and animal nutrition contexts). Researchers employ varied datasets and evaluation metrics to validate model performance, highlighting the need for standardized benchmarks and transparent validation protocols. There is also increasing recognition that contextual factors

including regional practices, breed differences, and cultural feeding patterns must be incorporated to ensure equitable and practical deployment of AI-driven nutrition systems (Akintan et al., 2024).

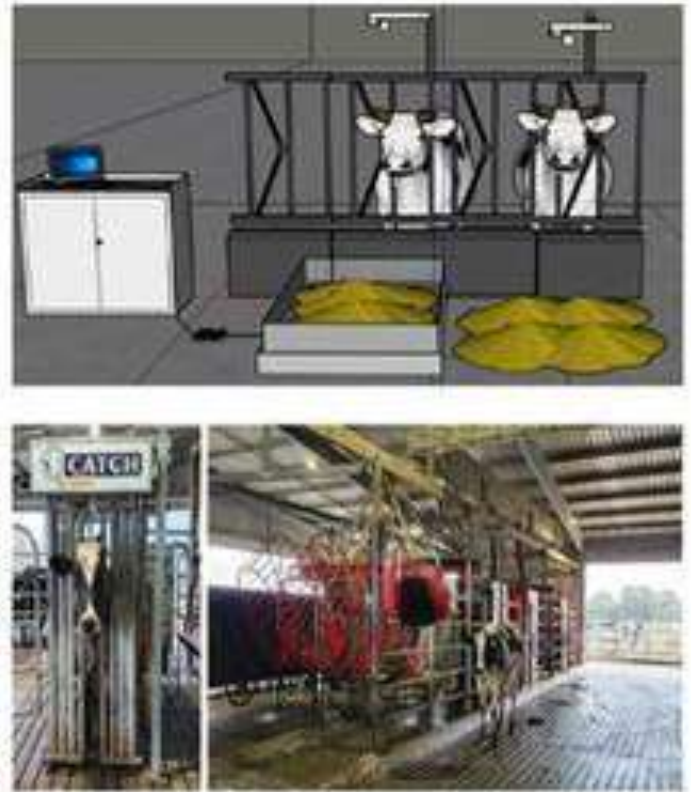


Fig. 2 AI animal feeding

### 4. AI in Behaviour and Welfare Monitoring

Artificial intelligence has become a key enabler of behaviour and welfare monitoring within precision livestock farming systems, particularly in response to the growing scale and intensification of meat and dairy production. Large herd sizes and continuous production cycles make manual welfare assessment difficult, creating the need for automated, objective, and continuous monitoring solutions. AI-powered precision livestock farming integrates cameras, environmental sensors, and wearable devices with machine learning and computer vision models to collect and analyse real-time data on animal posture (Fig. 4), movement, body condition, and interactions. This data-driven framework supports early detection of welfare risks, improves compliance with animal welfare standards, and enables targeted, animal-level



interventions while maintaining farm productivity and sustainability goals (Michielon et al., 2024).

Vision-based AI systems are increasingly used to automate key welfare indicators that traditionally require trained personnel, such as locomotion score, body condition score, posture, and behavioural activity. Multi-camera setups combined with deep learning detection, tracking, and pose-estimation models allow continuous monitoring of animals moving through barn (Fig. 3) corridors or housed in pens. From video streams, AI models can extract gait features, back posture, step patterns, and body shape metrics to estimate lameness risk and nutritional status (Congdon et al., 2022). Behaviour-oriented pipelines further quantify activity time budgets, distance travelled, standing and lying behaviour, and social or object interactions. These automated assessments provide both numerical scores and visual evidence, improving interpretability and enabling early warnings for conditions such as lameness, metabolic stress, or abnormal inactivity.

Recent developments emphasize modular AI architectures and edge-computing deployment, allowing welfare monitoring models to run directly on on-farm hardware without permanent cloud connectivity. Such systems support near real-time inference using optimized deep learning models and parallel processing on GPUs, making them practical across different farm sizes and infrastructure levels. AI-generated welfare metrics can be integrated into broader digital farm platforms that aggregate data from cameras, environmental sensors, and wearable devices, enabling continuous and federated farm monitoring. In addition, vision-based AI outputs can be used to calibrate and validate wearable sensor systems, improving the reliability of multimodal welfare assessment. Together, these advances demonstrate that AI-driven behaviour and welfare monitoring can deliver scalable, continuous, and objective evaluation frameworks for modern livestock production systems.



Fig.3 Cattle monitoring

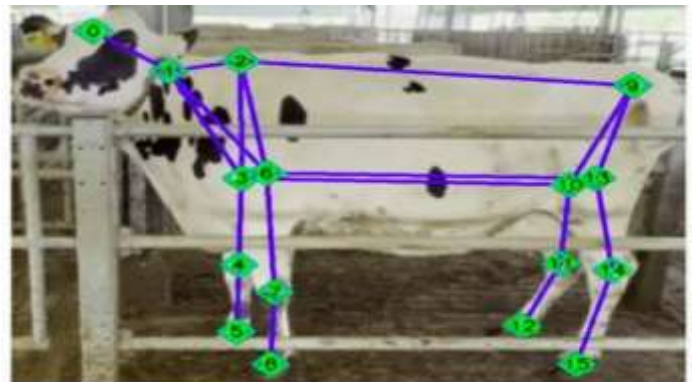


Fig. 4 Posture assessment

## 5. AI in Dairy Farm Automation

The dairy industry is experiencing rising pressure to improve productivity, sustainability, product quality, and animal welfare while meeting rapidly growing global demand. Artificial Intelligence (AI) has emerged as a transformative technology that enables data-driven decision-making across the dairy value chain, from herd management to processing and product development. By integrating machine learning, deep learning, big data analytics, and predictive algorithms, AI systems can convert large volumes of farm and processing data into operational insights. These capabilities support precision herd monitoring, optimized resource use, and improved production efficiency. AI combined with Internet of Things (IoT) infrastructure further strengthens traceability and compliance by enabling continuous tracking of animals, milk, and dairy products through interconnected sensor networks.



At the farm level, AI-driven tools support animal performance optimization through automated health monitoring, disease detection, reproductive management, precision nutrition, and milk yield prediction. Computer vision and sensor-based systems enable real-time assessment of animal condition, behaviour, and welfare, while predictive models assist in early disease warning and breeding decisions. Beyond the farm, AI applications extend into dairy processing and manufacturing, where intelligent systems are used for quality control, defect detection, process parameter optimization, and energy-efficient operations. Advanced analytics and pattern recognition models are also being used in product development to predict flavour, texture, and consumer acceptance, enabling customized dairy products aligned with market preferences.

Big data analytics plays a complementary role by processing high-volume, high-velocity, and high-dimensional datasets generated across dairy operations. These analytics platforms improve demand forecasting, supply chain optimization, food safety monitoring, and waste reduction, offering strong competitive advantages. Despite these benefits, AI adoption in the dairy sector faces challenges related to data privacy, ethical considerations, infrastructure requirements, and technical skill gaps. Current research is therefore focused not only on expanding AI applications but also on addressing implementation barriers and developing robust, transparent, and scalable AI frameworks tailored to dairy systems (Khanashyam et al., 2025).



Fig. 5 AI milking system

## 6. Conclusion

Artificial intelligence is transforming livestock and dairy management by enabling continuous monitoring, predictive analysis, and precision decision-making across animal health, behavior, nutrition, reproduction, and production systems. Through the integration of machine learning, computer vision, IoT sensors, and big data analytics, AI supports early disease detection, welfare assessment, precision feeding, yield optimization, and automated quality control in dairy processing and product development. These data-driven approaches improve productivity, sustainability, and animal welfare while reducing labor dependency and operational inefficiencies. However, widespread adoption still faces challenges related to cost, data reliability, technical expertise, ethics, and data governance. Continued advances in explainable AI, edge computing, and scalable smart-farm architectures are expected to overcome these barriers and establish AI as a foundational technology for efficient, sustainable, and welfare-oriented livestock systems.

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# In-situ decomposition of Sugarcane trash for a Cleaner and Productive Future

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Sugarcane cultivation generates large amounts of crop residues in terms of trash, dry leaves, and tops, which are usually disposed through open-field burning. However, this practice helps for quick field clearance, but affects the soil health, reduces soil organic matter, eliminates beneficial microorganisms, and also leads to air pollution and greenhouse gas emissions. This review focus on in-situ decomposition of sugarcane trash serves as a sustainable and eco-friendly alternative for converting crop residues into valuable organic matter directly within the field. It requires microbial decomposers which helps to breakdown the lignocellulosic components such as cellulose, hemicellulose, and lignin. Efficient microorganisms, including bacteria, fungi, and actinomycetes, are effective in accelerating the decomposition rate, increasing the soil organic carbon, and soil nutrients. The factors like carbon-to-nitrogen ratio, moisture, temperature, and aeration, which collectively regulate microbial activity and decomposition efficiency. By adopting this practice helps for improving the soil physical properties, increasing microbial diversity, retaining soil moisture, decreasing weed growth, and the use of chemical fertilizer thereby mitigating environmental pollution and supporting carbon sequestration. Strengthening extension efforts, policies, and technology can promote large-scale adoption of in-situ decomposition, thereby contributing to sustainable, climate-smart sugarcane production systems.

## Introduction

Sugarcane is a perennial plant characterized by thick, fibrous stems. It is traditionally grown around 110 countries across tropical and temperate regions, covering a total cultivation area of approximately 27 million hectares (Mohamad, et al., 2019; Nunes, et al., 2020). However, sugarcane cultivation generates a large amount of waste in the form of trash, dry leaves and tops left in the field after harvest. On average, every hectare of sugarcane produces 10–15 tonnes of trash, which farmers often burn to clear the field quickly. Burning sugarcane trash quickly degrades soil quality by reducing soil organic matter (SOM), which serves as a vital energy source for soil bacteria. Healthy soils are characterized by high microbial activity, and microorganisms play a key role in nutrient cycling, organic matter decomposition, and soil formation. Additionally, burning poses significant health risks due to the release of pollutants such as smoke, dust, ash, and particulate matter including CO, NO<sub>2</sub>, and SO<sub>2</sub> that

can harm the lungs. Sugarcane trash also contains essential macro- and micronutrients, especially nitrogen and carbon, which are lost from the soil when it is burned (Pollution Control Agency, 2023). A sustainable solution lies in *in-situ* decomposition, which converts this waste into valuable organic matter right in the field, promoting cleaner and more productive farming.

## Effects of conventional methods of trash disposal

Open burning of sugarcane trash is a common but harmful practice. It reduces the soil pH, moisture content, organic matter, soil carbon and nitrogen and also releases carbon dioxide, methane, and particulate matter, contributing for air pollution and greenhouse gas emissions (Yadav, 2019).. Moreover, burning destroys beneficial soil microorganisms leading to long-term degradation of soil health. Therefore, a shift toward eco-friendly trash management is crucial for sustainable sugarcane production.



**Concept of *In-situ* Decomposition**

*In-situ* decomposition refers to the process of breaking down organic residues (like sugarcane trash) directly in the field where they are generated, using natural or microbial processes. Instead of burning or removing the residues, they are spread evenly on the soil surface, moistened, and treated with bio-decomposer cultures that accelerate their conversion into humus and nutrients. This process helps to reduce soil compaction and improve soil physical properties and retain soil moisture, suppress weeds, enhance soil structure, and provide macro nutrients like N, P, and K and also the micro nutrients within the same field offering both environmental and economic benefits to farmers (Surwase et al., 2024). The process of *in-situ* decomposition of sugarcane trash is presented in fig 1.



Fig 1: Process of *in-situ* decomposition of sugarcane trash

**Role of Microbial Bio-Decomposers**

Decomposition is a microbiological process that breaks down the organic substrate into a more stable end product (Khatoon et al., 2017). This process involves the coordinated activity of diverse microorganisms, primarily bacteria and fungi, each performing distinct functional roles during substrate breakdown. In addition, actinomycetes - a specialized group of filamentous bacteria are considered as the third major decomposer group due to their remarkable ability to degrade complex and recalcitrant compounds, including lignocellulosic

materials and other resistant organic substances. Several fungi, and specific strains of bacteria like *Trichoderma* spp., *Bacillus* spp., and *Aspergillus* spp. secrete enzymes that degrade cellulose, hemicellulose, and lignin, the main components of sugarcane trash (França et al., 2018). These microorganisms can produce enzymes and metabolites that help organic waste decompose faster and improve soil humus quality (Wei et al., 2023). Bio-decomposer formulations like the TNAU Biomineralizer contain a blend of these efficient microorganisms. When applied to trash under suitable moisture and temperature conditions, they rapidly break down the plant material into simpler organic compounds. These microbial activities not only reduce the bulk of residues but also enrich the soil with organic carbon and plant-available nutrients.

**Factors Influencing Decomposition Efficiency**

Several factors influence the rate and success of *in-situ* decomposition of sugarcane trash (Abhiram et al., 2025). One key aspect is the carbon-to-nitrogen (C:N) ratio. Since sugarcane trash has a high C:N ratio of about 80:1, the process can be accelerated by adding small quantities of nitrogen-rich materials such as urea, cow dung slurry, or green manure. Adequate moisture is also crucial, as microbial decomposers need water to function effectively. However too little moisture slows down their activity, while excess water creates anaerobic conditions that hinder proper breakdown. Temperature also plays a vital role in decomposition process. It needs warm and moderately moist conditions between 28°C and 35°C are ideal for microbial growth and enzymatic activity (Abhiram et al., 2025). Another important factor is aeration, as sufficient air circulation ensures aerobic decomposition, prevents foul odours, and promotes uniform degradation. By managing all these factors, farmers can ensure faster, efficient, and complete decomposition of sugarcane trash, transforming it



into nutrient-rich organic matter that enhances soil fertility and crop productivity.

### Benefits of *In-situ* Decomposition

Adopting this eco-friendly approach provides multiple benefits for both the soil and the environment. It significantly improves soil organic carbon, enhancing soil structure, porosity, and moisture retention ability which leads to healthier crop growth (Hiranmai et al., 2024). It also boosts microbial activity, encouraging beneficial microorganisms that aid in nutrient cycling and strengthen root health. As the decomposed trash releases nutrients gradually, it reduces the need for chemical fertilizers, lowering production costs and promoting natural soil fertility. In addition, the trash layer acts as a natural mulch, effectively suppressing weed growth and conserving soil moisture. Environmentally, this practice prevents pollution caused by burning residues and contributes to carbon sequestration, helping mitigate climate change (Dhanushkodi et al., 2023). Overall, *in-situ* bio-decomposition transforms agricultural waste into a valuable resource, supporting the vision of sustainable and climate-smart farming.

### Challenges and Future Prospects

Despite its proven benefits, adoption remains limited due to lack of awareness, initial labour requirements, and delayed results compared to burning. To promote large-scale implementation, training programs, government incentives, and demonstration fields are essential. Future innovations may include enhanced bio-decomposer strains, nanotechnology-based enzyme carriers, and AI-based decomposition monitoring systems, making the process faster and more farmer-friendly.

### Conclusion

*In-situ* decomposition of sugarcane trash represents a transformative step toward sustainable agriculture. It not only prevents pollution from residue burning but also rejuvenates soil fertility, enhances productivity,

and conserves environmental health. By integrating microbial biotechnology with smart farming tools, farmers can turn agricultural waste into wealth and paving the way for a cleaner and more productive future for sugarcane cultivation.

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# Silent Killer in Citrus Trunks: Field Observation from Yazali, Keyi Panyor, Arunachal Pradesh

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Citrus cultivation is an important horticultural activity in Arunachal Pradesh and contributes significantly to rural livelihoods. During the RAWE programme conducted in Yazali village of Keyi Panyor district, severe infestation of citrus stem borer was observed in orange orchards. Characteristic symptoms such as trunk holes, frass extrusion, bark damage, and internal tunnelling by creamy-white grubs were recorded. Infestation was more prevalent in neglected orchards and trees with trunk injuries. Farmers in the study area practiced traditional management by inserting petrol-soaked cotton or injecting petrol into borer holes to kill larvae. The observation highlights citrus stem borer as a hidden but serious threat to citrus health in the region and emphasizes the need for early detection and orchard sanitation practices.

## Introduction

Citrus cultivation is an integral component of horticulture-based livelihoods in Arunachal Pradesh, particularly in foothill and mid-hill regions (NHB, 2014). Despite favorable agro-climatic conditions, productivity of citrus orchards remains low due to poor management and pest incidence (Singh, 2000). Among trunk-damaging pests, the citrus stem borer (trunk borer) is one of the most destructive yet often unnoticed pests, causing gradual decline and death of trees (Beeson, 1941; Butani, 1979). During the RAWE programme conducted in Yazali village of Keyi Panyor district, stem borer infestation was observed in several orange plants across farmer orchards.

## Field Symptoms Observed in Yazali Orchards



Figure 1: Citrus trunk showing active stem borer infestation with bark removal, frass accumulation and tunnelling injury at mid-trunk region



Figure 2: Basal stem of orange plant exhibiting borer entry hole with frass extrusion and white fungal growth at collar zone

Circular holes on trunk and basal stem were observed, indicating larval entry and exit points (Beeson, 1941). Extrusion of wood dust (frass) from openings was a prominent symptom, produced during larval feeding inside wood (Verma & Prasad, 2001). Sap oozing and bark cracking near infestation site were also recorded, suggesting tissue injury and secondary infection. Drying of branches and canopy thinning occurred due to disruption of vascular tissues. Creamy-white grubs tunnelling inside wood confirmed active stem borer infestation. Advanced infestation resulted in weakening of trunk and gradual plant decline.

## Pest Identity and Biology



Figure 3: Internal tunnelling and creamy-white larvae of citrus stem borer exposed after splitting infested trunk

The citrus stem borer belongs to longhorn beetles (family: Cerambycidae), mainly species of Anoplophora and Batocera reported from citrus in



India. Adult beetles lay eggs in bark crevices or wounds on trunk and branches. After hatching, larvae bore into the trunk and feed internally for several months. Because feeding occurs inside wood, infestation remains unnoticed until external symptoms appear (Butani & Jotwani, 1984).

### Nature of Damage

Larval tunnelling disrupts vascular tissues responsible for water and nutrient transport. Continuous feeding reduces sap flow and weakens structural strength of the trunk (Butani, 1979). Borer holes also serve as entry points for decay organisms and pathogens. Severe infestation may result in branch breakage or plant mortality (ICAR-CCRI, 2018). In Yazali orchards, heavily infested trees showed progressive canopy thinning and reduced vigor.

### Incidence Pattern in Yazali Area

Higher infestation was observed in old and neglected citrus orchards, which favour pest survival. Trees with mechanical injuries were more affected because wounds facilitate egg laying. Orchards with dense shade and high humidity also showed increased incidence. Plants with soil or mulch touching trunk base were more susceptible due to bark softening and pest entry.

### Management Practices Observed in Farmers' Fields

- i. Farmers inserted iron wire or stick into holes to mechanically kill larvae, which is a commonly recommended physical control method for trunk borers.
- ii. Frass and loose bark were removed to expose tunnels.
- iii. Cotton soaked in petrol was inserted into borer holes or petrol was injected using syringe to kill larvae by fumigation effect.
- iv. Holes were sealed with mud to retain fumes inside, ensuring larval mortality. Such traditional

- fumigation practices are widely adopted by farmers against concealed borers in tree crops.
- v. Preventive measures such as maintaining trunk hygiene, avoiding injury, and regular orchard inspection are essential to reduce infestation.

### Conclusion

The citrus stem borer acts as a “silent killer” in citrus orchards due to its concealed feeding habit within trunks. Field observations during the RAWI programme at Yazali confirmed active infestation and plant decline in orange orchards. Farmers relied on petrol-based traditional control methods to manage larvae inside trunks. Early detection and improved orchard sanitation are essential to reduce infestation and sustain citrus productivity in Keyi Panyor district and similar citrus-growing areas of Arunachal Pradesh.

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# Genuine Genetic Purity of Seeds: Bridging India's Yield Gap through Ethical Seed Entrepreneurship

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Seed quality represents the most critical determinant of crop productivity, particularly in high-value vegetable production systems where genetic potential governs yield stability, uniformity, and input-use efficiency. Despite being the world's second-largest vegetable producer, India continues to exhibit substantially lower productivity compared to technologically advanced agricultural systems. A key factor underlying this disparity is the widespread circulation of spurious and genetically impure seeds, including mislabelled hybrids and unauthorized second-generation ( $F_2$ ) seed material, which leads to poor crop performance, loss of farmer confidence, and severe economic losses. Recent regulatory interventions, notably the proposed Seeds Bill (2025/26), aim to strengthen quality control and penalize counterfeit seed markets, thereby reshaping the seed sector. Advances in seed science, such as molecular marker-based purity testing, digital traceability systems, and contract-based seed production models, provide new opportunities for ethical seed entrepreneurship. The integration of genetic authenticity with transparent business practices emerges as a sustainable pathway for narrowing India's productivity gap, improving farmer livelihoods, and reinforcing national food and nutritional security.

## Introduction

Indian agriculture is confronting a largely invisible yet economically destructive crisis where the widespread circulation of spurious, misbranded, and genetically inferior seeds within both formal and informal seed markets. Seed quality is universally recognized as the most critical input in crop production, accounting for a substantial proportion of yield realization and input-use efficiency (Acquaah, 2020; FAO, 2021). When seed quality is compromised, investments in fertilizers, irrigation, plant protection chemicals, labour, and mechanization fail to translate into productive output, resulting in systemic yield losses and heightened production risk for farmers. National assessments have consistently emphasized that poor-quality seed undermines agricultural productivity, inflates cultivation costs, and weakens the effectiveness of public investment in agriculture, particularly in high-value horticultural and hybrid crops (Government of India, 2023; NITI Aayog, 2024). Spurious seeds in India typically take several forms, including repackaged food grain sold as certified seed,

unauthorized varieties falsely labelled as notified cultivars, and second-generation ( $F_2$ ) seed material marketed as first-generation ( $F_1$ ) hybrids. Such practices violate basic principles of plant genetics, as  $F_2$  seeds inherently segregate for yield, quality, and resistance traits, leading to severe non-uniformity and yield instability (Kumar *et al.*, 2022; Acquaah, 2020). Empirical studies have shown that the use of genetically impure hybrid seed can reduce marketable yield by 30–60 per cent in vegetable crops, particularly in tomato, chilli, capsicum, and brinjal (Singh & Singh, 2021).

The scale of this problem has been repeatedly highlighted through enforcement actions and investigative journalism. According to data released by several State Agriculture Departments and reported by national media, thousands of cases of fake seed sales are registered annually, with major crackdowns reported in Telangana, Andhra Pradesh, Maharashtra, Uttar Pradesh, and Madhya Pradesh during recent cropping seasons (Times of India, 2024; The Hindu, 2023). In Telangana alone, enforcement agencies reportedly seized spurious



cotton and vegetable seeds worth over ₹100 crore during a single Kharif season, exposing organized interstate networks involved in seed adulteration and misbranding (The Hindu, 2023). Similar reports from Uttar Pradesh and Maharashtra document repeated instances where unlicensed dealers sold counterfeit hybrid vegetable seeds, leading to complete crop failure and farmer protests (Times of India, 2024).

Beyond individual farm losses, the economic implications of faulty seed usage extend to the national level. The Ministry of Agriculture has consistently reported that seed-related failures significantly contribute to yield gaps and income instability, particularly in high-value horticultural crops (GOI, 2023). While the upfront cost of spurious seed typically ranges between ₹1,500 and ₹2,500 per acre, the indirect losses are substantially higher. Once expenditure on fertilizers, agrochemicals, irrigation, labour, staking, and harvesting is accounted for, total losses can escalate to ₹40,000–60,000 per acre in vegetable crops, with even higher figures reported under protected cultivation systems (NITI Aayog, 2024). At a macro scale, such failures undermine national productivity targets, inflate input subsidies, and weaken the efficiency of public investment in agriculture.

The persistence of spurious seeds also erodes farmer trust in formal seed systems, driving reliance on informal markets where regulatory oversight is minimal. This creates a self-reinforcing cycle of low productivity, risk aversion, and technological stagnation. Recognizing the structural threat posed by counterfeit seed markets, the Government of India has proposed comprehensive regulatory reform through the Draft Seeds Bill (2025/26). The Bill mandates compulsory seed registration, enhanced traceability, and stringent penalties—including fines up to ₹30 lakh and imprisonment—for the manufacture and sale of misbranded or substandard seeds (GOI, 2024). While primarily designed as a farmer-protection mechanism, the evolving regulatory framework simultaneously reshapes the

seed sector by creating space for transparent, science-driven, and ethically grounded seed enterprises.

In this context, genuine seed entrepreneurship anchored in genetic purity, regulatory compliance, and farmer accountability emerges as a critical intervention for restoring confidence in seed systems. By addressing the root causes of yield instability through authentic genetics rather than short-term commercial exploitation, ethical seed enterprises have the potential to transform seed from a source of risk into a driver of productivity, resilience, and national food security.

### 1. The Productivity Gap: A Genetic Perspective

India ranks as the second-largest producer of vegetables globally, contributing more than 205 million tonnes annually; however, productivity per unit area remains significantly below global benchmarks (FAO, 2023). Average vegetable yields in India range between 15–25 t ha<sup>-1</sup>, whereas several technologically advanced and horticulturally intensive countries consistently achieve yields two to ten times higher under both open-field and protected cultivation systems. **Table 1: Yield comparison of productive countries with India for vegetables**

Crop	Country	Average Yield (t ha <sup>-1</sup> )	India (t ha <sup>-1</sup> )
Tomato	Netherlands (Protected cultivation)	450–500	22–25
Tomato	Spain	85–100	22–25
Tomato	USA	95–110	22–25
Capsicum	Israel	120–150	18–22
Capsicum	Netherlands (Greenhouse)	300–350	18–22
Brinjal	China	35–40	18–20



Onion	Republic of Korea	65–70	22–25
Cucumber	Japan	90–110	20–25

(FAO, 2023; ICAR-IIHR, 2022)

The superior productivity observed in countries such as the Netherlands, Israel, Spain, Japan, and the USA is attributed to a combination of genetically superior hybrids, strict seed quality regulation, protected cultivation technologies, and precision input management. Among these factors, genetic potential embedded within high-quality seed material plays a decisive role. Empirical studies indicate that 25–40% of realized yield variation in vegetables can be directly attributed to seed genetic quality, particularly in hybrids where heterosis expression is critical (Acquaah, 2020; Singh & Singh, 2021).

In contrast, Indian farmers frequently cultivate genetically inferior or segregating planting material, often unknowingly, due to the prevalence of spurious seeds in informal markets. The use of F<sub>2</sub> hybrid seed or untested local selections leads to non-uniform plant populations, asynchronous flowering, poor fruit set, and reduced resistance to biotic and abiotic stresses. These genetic limitations not only suppress yield potential but also reduce the efficiency of fertilizers, irrigation, and plant protection inputs, thereby widening the productivity gap despite comparable agronomic efforts.

Thus, the observed yield disparity between India and leading vegetable-producing nations is not merely a consequence of resource availability or climatic conditions; rather, it reflects a fundamental genetic yield gap, rooted in seed purity, varietal adaptability, and the integrity of the seed supply chain.

## 2. Industry Landscape and the Trust Deficit

India’s organized seed sector includes several well-established firms that have contributed significantly to hybrid development, particularly in vegetables, cotton, and maize. These companies invest heavily in

breeding programs, multi-location trials, and quality assurance systems (Pray & Nagarajan, 2014).

Despite their scale and technological capacity, large seed companies cannot address micro-regional varietal needs, such as:

- Local consumer preferences (fruit shape, colour, pungency)
- Region-specific stress tolerance
- Traditional vegetable niches tied to local markets

Consequently, farmers in such regions rely on unorganized seed sellers, where the risk of adulteration is highest. This structural gap presents a strategic entry point for localized, ethical seed entrepreneurs capable of producing region-specific, genetically pure seed lots under scientific supervision.

## 3. The Opportunity: Scientific and Digital Implementation

### 3.1 Seed Traceability Systems

Modern seed enterprises can differentiate themselves by adopting digital traceability tools, such as QR-coded seed packets. When scanned, these codes can provide farmers instant access to:

- Germination test results
- Genetic purity reports
- Production location and season
- Certification details

Such systems have been shown to significantly improve farmer confidence and brand loyalty (World Bank, 2024).

### 4.2 Molecular Purity Testing

Genetic purity is the cornerstone of hybrid seed performance, as even minor contamination can significantly reduce heterosis and yield uniformity.



Conventional grow-out tests (GOT), although widely used, are time-consuming, environment-dependent, and often inadequate for detecting low levels of genetic admixture. In contrast, DNA-based molecular marker techniques, such as Simple Sequence Repeats (SSR), Single Nucleotide Polymorphisms (SNP), and Sequence Characterized Amplified Regions (SCAR), provide rapid, precise, and reproducible assessment of genetic purity in hybrid seed lots (Rao *et al.*, 2019).

Molecular purity testing enables the identification of off-types at early stages, ensuring compliance with certification standards and minimizing the risk of farmer-level crop failure. Studies have demonstrated that molecular markers can detect genetic impurities as low as 1–2%, which are often missed by morphological evaluation (Rao *et al.*, 2019). For ethical seed entrepreneurs, collaboration with accredited molecular laboratories allows third-party validation of genetic integrity, thereby enhancing transparency and brand credibility.

The adoption of molecular diagnostics also supports regulatory compliance under emerging seed laws that emphasize traceability and quality assurance. By integrating molecular purity certification into routine quality control protocols, seed enterprises can establish a scientifically verifiable guarantee of genetic authenticity, effectively differentiating themselves from unregulated operators and counterfeit seed suppliers.

**4.3 Contract Seed Production Models**

Rather than owning land, ethical entrepreneurs can adopt contract seed production, acting as quality controllers. Under this model:

- Farmers produce seed crops under buy-back agreements
- Entrepreneurs supply breeder/foundation seed
- Field inspections ensure isolation, rouging, and genetic conformity

This approach minimizes capital costs while maximizing genetic and physical seed quality (George *et al.*, 2020).

**5. Constraints and Practical Solutions**

<b>Constraint</b>	<b>Scientifically Viable Solution</b>
<b>High R&amp;D Investment</b>	Instead of initiating de novo breeding programs, startups can license released varieties and parental lines from public institutions such as ICAR institutes (IIHR, IARI), State Agricultural Universities, National Seed Corporation (NSC), State Seed Corporations, and Krishi Vigyan Kendras through formal MoUs. This significantly reduces breeding costs while ensuring genetic reliability.
<b>Regulatory Complexity</b>	Early engagement with seed certification agencies and regulatory consultants facilitates compliance with seed licensing, registration, and quality SOPs, minimizing delays and legal risks.
<b>Long Gestation Period</b>	Entrepreneurs can initially focus on seed processing, treatment, packaging, and marketing of certified seed before transitioning to hybrid breeding and parental line development.
<b>Farmer Trust Deficit</b>	Establishment of demonstration plots, field days, and participatory varietal evaluation builds farmer confidence and allows visual assessment of crop performance prior to seed purchase.

Evidence from extension studies indicates that demonstration-based seed dissemination enhances adoption rates by 30–45%, particularly among small and marginal farmers, by reducing perceived risk and improving trust in seed quality (ICAR, 2022).



## Conclusion

India's agricultural future does not hinge solely on technology or capital—it depends on integrity embedded within the seed itself. Genuine seed entrepreneurship represents a unique convergence of science, service, and sustainability.

Agriculture does not merely require more entrepreneurs; it demands agri-ethicists—individuals committed to genetic authenticity, farmer welfare, and national food security. With profit margins ranging from 40–50% in organized vegetable seed markets, ethical seed production is not only economically viable but morally imperative.

Producing genuine seeds is more than a business, it is a national service rooted in genetics, trust, and responsibility.

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# Residual Shadows: Managing Growth Inhibitors in Fruit Orchards

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## The Power and The Problem

Plant growth inhibitors, commonly known as growth retardants, are synthetic plant growth regulators used in agriculture to suppress excessive vegetative growth, enhance lodging resistance, and improve yield quality in crops like cereals, fruits, and vegetables. Their residual effects in soil, however, can persist for weeks to months, impacting subsequent crops and raising environmental concerns.

## Why Growth Inhibitors Changed Everything

Pacllobutrazol (PBZ), a triazole, inhibits gibberellin biosynthesis, reducing internode elongation and promoting compact growth. Chlormequat chloride (CCC) and mepiquat chloride, quaternary ammonium compounds, similarly retard stem elongation in cereals and enhance flowering and fruiting in fruit crops

- **Mango:** PBZ (2-3g AI/tree) cuts vegetative shoots 50-70%; panicle emergence rises 80%.
- **HDP Revolution:** Compact canopies fit 800-1,200 trees/ha vs. 250 traditional.
- **Biennial Fix:** Regular PBZ cycles eliminate mangos notorious 'off' years.
- **Citrus:** CCC reduces ladder dependence, pruning costs down 30%.

## Dose Reference Table:

Inhibitor	Crop	Rate	Timing	Mode
PBZ (25% SC)	Mango	2-3g AI/tree	Post-harvest	Soil basin

			(Aug-Sep)	
Chlormequat	Apple	2,000ppm	Pre-bloom	Foliar
Prohexadione-Ca	Pear	125g/ha	Post-bloom	Foliar

## The Residue Reality

### What Stays in Soil and What Reaches Your Fruit

PBZ's triazole ring structure binds tightly to clay and organic matter, resisting microbial breakdown. Topsoil (0-15cm) half-life: 6-12 months. With repeat applications every 2-3 years, soil levels peak at 1-2ppm measurable,

Fruit residues tell a different story. LC-MS/MS analysis confirms: Unripe mango pulp holds 0.1-0.5ppm immediately post-treatment. By commercial maturity (90-120 days later), levels drop to undetectable (<0.01ppm) well within India's maximum residue limit (0.5ppm) and European Union strict 0.05ppm limit.

### Critical Residue Reference:

Inhibitor	Soil Persistence	PHI (Days)	Fruit at Harvest	MRL India/EU
<b>PBZ</b>	2-5 years	90-120d	Non-detectable	0.5/0.05ppm
<b>Chlormequat</b>	2-4 months	30d	Negligible	0.05/0.05ppm



<b>Prohexadione-Ca</b>	6-12 months	21d	Trace	0.1/0.1ppm
<b>Daminozide</b>	1 season	60d	Low if timed	Banned EU

PHI- Pre-Harvest interval, MRL-Maximum residue limit, EU- European Union

### Hidden Ripples: Microbes, Ecosystem, Human Health

Soil biology bears a temporary toll. PBZ suppresses N-fixing and nitrifying bacteria 20-30% in 1<sup>st</sup> Year. The good news: biodiversity fully recovers by 3<sup>rd</sup> Year, especially with organic amendments.

Environmental risk is low under correct use of PBZ does not leach below 30cm in loamy/clay soils. Sandy soils near water bodies demand extra caution. No peer-reviewed study links field-rate PBZ exposure to chronic human health effects at current MRLs.

### Misuse and Overdose Risks:

- Overdose (>5g/tree) causes permanent dwarfism, no remedy.
- Saline soils bind PBZ longer; extend PHI by 30 days.
- Rain within 48h of application reduces uptake and risks runoff.

### Smart PBZ Use: Step-by-Step Protocols

Science is clear: Disciplined use keeps PBZ profitable and export-safe. Follow this validated protocol step-by-step

#### Before Application:

- Soil test mandatorily; proceed only if PBZ <0.5ppm.
- Check rainfall forecast — apply only during dry spells.

- Calculate exact tree basin area (1-1.5m radius, 1.25-2.5g AI/tree).

#### During Application:

- Mix PBZ in 10L water per tree; drench evenly in basin.
- Apply post-harvest (August-September), not pre-bloom.
- Record date, dose, and batch for export documentation.

#### Post-Application Residue Reduction:

- Deep plough (30cm) in Year 4 dilutes soil buildup 50%.
- Incorporate biochar (5t/ha) — adsorbs 60-70% residues.
- Plant cover crops (legumes) to accelerate microbial recovery.
- Harvest strictly after 90-120-day PHI — test random fruits Rs 2,000/sample before EU export.

### Green Alternatives Rising

Farmers now blend inhibitors with biological options for residue-lite orchards

- **Seaweed Extracts (2-3ml/L):** Reduce shoot growth 35-40%, zero soil residue.
- **Mechanical Hedging/Root Pruning:** Dwarfs canopy without chemistry.
- **Prohexadione-Ca:** Faster breakdown (6 months), lower MRL risk — ideal EU-export blocks.
- **Nano-Inhibitors (Emerging):** Targeted release, biodegrades in weeks.

Hybrid strategy — PBZ Year 1, seaweed + pruning Year 2-3 — reduces soil buildup 60% while maintaining compact vigour and yields



### Profits: Numbers That Settle Nerves

Investment	Return	Net Gain
PBZ app Rs 800/tree	Yield +100% (7→14t/ha)	Rs 2.5 lakh/ha
Soil test Rs 500	Export clearance	Rs 50k+ premium
Biochar Rs 8,000/ha	Residue -60%	Export security

### Conclusion: Test, Time, and Thrive

Growth inhibitors are not villains, they are misunderstood tools. Used with soil-testing discipline, correct dosing, and harvesting at PHI, PBZ delivers clean, high-value fruits consistently. Horticulture future lies in orchards that combine inhibitor power with biochar, seaweed, and smart timing.

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# Transboundary Livestock and Poultry Diseases in Arunachal Pradesh: A Silent Threat to Tribal Livelihoods

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## 1. Introduction

Arunachal Pradesh, popularly known as the “Land of the Rising Sun”, is the easternmost state of India. The state shares long international borders with Bhutan, Tibet and Myanmar, besides interstate borders with Assam and Nagaland. This unique geographical location, porous borders, free movement of livestock and traditional grazing systems make the state highly vulnerable to transboundary animal diseases (TADs). These diseases spread rapidly across regions and cause serious losses to livestock-dependent tribal communities.

## 2. Importance of Livestock and Poultry in Arunachal Pradesh

Livestock such as cattle, mithun, pigs, goats, sheep, yak and poultry play a pivotal role in sustaining rural livelihoods. Apart from providing milk, meat and eggs, livestock are closely associated with socio-cultural traditions and religious practices of tribal societies. Disease outbreaks therefore directly affect income, food security and rural stability.

## 3. Major Transboundary Livestock and Poultry Diseases

### 3.1 Foot-and-Mouth Disease (FMD)

Foot-and-Mouth Disease is a highly contagious viral disease affecting cattle, pigs, sheep and goats. In Arunachal Pradesh, Mithun (*Bos frontalis*) is particularly susceptible due to its semi-wild grazing habit and interaction with wild animals. The disease causes fever, mouth and foot lesions, lameness and sharp decline in productivity. Morbidity is very high, and mortality in mithun may exceed 60% during severe outbreaks. Virus types O, A and Asia-1 are prevalent, with Type O dominating in Northeast India.



Picture No. 1 Foot & Mouth disease in Mithun (*Bosfrontalis*)

### 3.2 Classical Swine Fever (CSF)

Classical Swine Fever, also known as Hog Cholera, is one of the most devastating diseases of pigs. It affects pigs of all ages, with mortality reaching up to 100% in unvaccinated herds. Clinical signs include



high fever, depression, skin discoloration, nervous symptoms and diarrhea. Typical post-mortem lesions include “turkey egg” kidneys and necrotizing enteritis. Regular vaccination and strict biosecurity are essential for prevention.



Figure 2. Patechial Haemorrhage in skin & Necrotizing enteritis in intestine

### 3.3 African Swine Fever (ASF)

African Swine Fever is a highly fatal transboundary viral disease of domestic and wild pigs, causing enormous economic losses. The disease has emerged as a major threat to pig farming in Northeast India, including Arunachal Pradesh.

- Mortality may reach up to 100%
- No effective vaccine or treatment is currently available
- Clinical signs include high fever, loss of appetite, skin hemorrhages, bluish discoloration of ears and sudden death

ASF spreads through direct contact, contaminated pork products, swill feeding and movement of infected animals. Strict biosecurity, control of pig movement and awareness among farmers are the only effective control measures.



Figure 3. Blood oozing from eyes & Conjunctivitis with mucopurulent discharge

### 3.4 Brucellosis

Brucellosis is a chronic bacterial disease caused by the bacterium *Brucella abortus* mainly affecting cattle and buffaloes, leading to abortions, infertility and reduced milk production. It is also a zoonotic disease, posing a public health risk to farmers and veterinarians through direct contact with infected animals or consumption of raw milk..



Fig.4 Aborted fetus of cattle

### 3.5 Newcastle Disease (ND)

Newcastle Disease is one of the most fatal viral diseases of poultry, The causative agent, NDV is also known as Avian Paramyxovirus type 1 (APMV-1) and the only member of the genus of *Avulavirus* in the family Paramyxoviridae. especially in backyard production systems. Mortality may reach 90–100% in unvaccinated birds. The disease causes respiratory distress, nervous signs and severe drop in egg production. Routine vaccination is the most effective control strategy.



Fig.5. Symptom showing symptom of Newcastle disease and death flock

### 4.Preventive Measures and Way Forward

- Ring vaccination against FMD in border areas
- Barrier vaccination in endemic zones twice yearly

- Mandatory vaccination against CSF in pigs
- Regular Newcastle Disease vaccination in backyard poultry
- Improved farm biosecurity and controlled animal movement
- Farmer awareness and early disease reporting

### 5. Conclusion

Transboundary livestock diseases pose a major challenge to livestock development in Arunachal Pradesh. Considering the heavy dependence of tribal communities on livestock, preventive vaccination, strengthened biosecurity and farmer education are essential to safeguard animal health, ensure food security and sustain rural livelihoods.

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## Broom grass cultivation in the abandoned jhum land for sustainability and income generation

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Broom grass (*Thysanolaena maxima* (Roxb.) O. Ktze) of the family Poaceae is a tall, tufted, reed-like perennial grass which grows well along hill sides (Bor 1960; Clayton and Revoize 1986). It is found on the slopes of hills, damp steep banks along ravines and on sandy banks of the rivers. It is distributed widely throughout the country up to an altitude of 2000 m. It grows in tussocks and on an average 4-5 tussocks are found in 10m<sup>2</sup> area. The culms arise centrifugally during the peak growing season (April to July) and bear inflorescence (panicle) on shoot apex at the end of vegetative growth. The inflorescence that is about 30 to 90 cm long resembles a foxtail and used as broom. This species is very common throughout the North East India.

Broom grass is a perennial, high value, non-perishable cash crop for wide range of agro-climatic conditions. It is a multipurpose species which provides brooms, fuel, fodder and has high soil conservation value. It is usually available in large quantities from July to February and is used as cattle feed in the period of fodder scarcity. The decoction of roots of this plant is used as mouth wash during fever. It has the comparative advantage of tolerance to harsh environmental conditions such as steep rocky mountain slopes, shallow soil, drought and high rainfall conditions. The grass can be successfully grown in the hilly tracts even in the degraded *jhum* fallowlands in the region. It is a multipurpose species which provides brooms, fuel, and fodder and has high soil conservation value. The brooms made out of this grass are more durable than

other plants such as *Cocos nucifera* and *Phragmites species*. Its cultivation can also promote the sustainable use of fragile and degraded lands. The productivity of grass depends on quality of planting material (Bisht and Ahlawat,1998). Therefore, it is suitable to grow on wastelands, *jhum* fallow, as well as in homesteads. The fibrous root system of the plant is very useful in checking soil erosion on steep slopes. The cultivation of this grass can wean away the practice of shifting cultivation and reduce the dependence of people on forests.



Shifting cultivation or *Jhum* is the main form of agriculture in the hilly parts of North Eastern region of India. It is also widely practiced in Churachandpur District, Manipur. As shifting cultivation involves clearing of forest, the practice is often considered ecologically harmful. It is also regarded that shifting cultivation leads to loss of soil fertility, erosion and soil run off. *Jhum* is the most serious problems leading to degradation of forest. It affects the forest cover adversely by clearing of the hill slopes through slash and burning of vegetation. The *Jhum* cycle period has been reduced to 2-3 years from 5-10 years,



leading to vast area under abandoned jhumland. To overcome some the major shortfalls associated with shifting cultivation, cultivation of broom grass in jhum fallow was introduced for sustainability.

### **Morphology**

Huge tufted grass, up to 3 m tall, culms solid, leaf-sheaths at least the upper ones, tight, glabrous, terete, smooth, the nodes glabrous, margins with some short stiff hairs towards the throat; blades lanceolate-acuminate, abruptly contracted to a short petiole for a subcordate base, acuminate to a fine point, glabrous, the margins scaberulous, up to 50 cm long and 7 cm wide; ligule a shallow membrane 1-2 mm deep, backed by short stiff hairs; Inflorescence a huge and drooping panicle 60 - 90 cm long or more wide at anthesis, the axis and branches at first rounded, ultimately, capillary, not sharply angled; spikelets numerous, often in pairs on a common peduncle, each pedicel distinct; lower glume clasping, ovateacute, obscurely 1 nerved, up to 6.5 mm long; upper glume more transparent; lower-lemma lanceolate-acuminate, sub-hyaline, with 1 or 2 long setose hairs near the margin; upper lemma lanceolate-acuminate, 3 nerved, green between the nerves, hyaline thence to the margin, with stiff setose hairs along the hyaline portion on both sides; palea a narrow, 2 nerved, hyaline scale; stamens 2 (3); stigmata 2, plumose; reddish brown, the rachilla continues as a flattened process with an expanded tip, beyond and behind the upper lemma. The aspect of the spikelet's changes with the onset of anthesis when the upper lemma emerges, and its setose hairs gradually adopt a stance at right angles to the lemma's surface.

### **Natural regeneration**

It regenerates through seeds under natural condition. The seeds mature during February to March and disseminate by wind to long distances due to their light weight. Seed dispersal is also affected by water in some areas. The seed germinates in the beginning of the rainy season. The seedling establishment and

the growth is good on loose and exposed areas such as landslides and freshly disturbed soil especially near road construction sites where light availability is good.

### **Artificial regeneration**

Cultivation of broom-grass is comparatively easy and requires fewer financial inputs. It can be grown on marginal lands, wastelands and jhum fallow. It grows well on a wide range of soils varying from sandy loam to clay loam. The planting can be done by seeds or rhizomes. Some people also collect and transplant the wild seedlings for propagation, but it is always better to get quality seedlings from reputed nurseries.

### **Nursery techniques**

It can be propagated artificially through seeds, rhizomes and wild seedlings transplant. The seeds are generally available in March from senescing panicles. Small mother beds 2m x 1 m are prepared and sowing is done by broadcasting 5 to 10 g seeds in each bed. Seeds are covered with very thin layer of sand and the beds with thatch grass. Watering is done as and when required. The germination starts after two to three weeks of sowing. The grass cover is removed on germination of seeds and regular weeding and watering is done. After 4 to 6 weeks the seedlings are either transplanted to other beds at a spacing of 10 cm x 10 cm or in the polythene bags filled with a mixture of soil, sand and farm yard manure in a ratio of 1:2:1. Watering and weeding is done regularly till the seedlings are ready for planting in field in the beginning of next rainy season. The propagules/rhizomes (roots along with culms) are collected by digging of roots from wild or cultivated plants after harvesting the crop during February or March. The culms are cut leaving 15-20 cm long stem with roots and used for raising nursery as well as for planting in the field. Two to three culms along with bud sprouts and rhizomes are separated from clump and planted either in polybags or in field. The mixture of topsoil, sand and farmyard manure in 1:2:1 ratio is used for filling the polybags or pits. During



transplanting the soil should have sufficient moisture for plant establishment. The plants are watered as and when required and kept in shade. The rhizomes are easy to transport to long distances for propagation as well as for plantation. The cut ends of culms can be dipped in melted wax to prevent drying and decaying. A small clump of rhizome having culms of 4 to 5 nodes is good for planting and almost cent per cent result is obtained by this method. The sprouted rhizomes are ready within three months for transplanting in the field.



### Site development and planting

The planting site must be clean and free from weeds. Thorough jungle cutting should be done before or during March and debris are either burnt or removed from the field. The pits of 30 cm<sup>3</sup> are dugout one month before the planting and left for weathering. A spacing of 2.5 m x 2.5 m is the best for plain fertile land and 1600 seedlings are required for planting of one-hectare area. While for jhum lands or hilly areas planting in contour lines or on the bunds of terraces at a spacing of 1.5 x 2.0 m is good and about 2500 to 4000 plants are required for one-hectare area. The spacing may vary with the type of land being used for cultivation. However, good yield can be obtained when it is cultivated on fertile lands. It is generally planted at the onset of monsoon during May - June, when soil has sufficient moisture for plant establishment. Several culms sprout from each plant resulting into a clump of culms from every pit. It does not require much care after planting. However, 3 to 4 weeding and soil working in the first year and three similar operations in subsequent years are necessary

for obtaining good return. Farmyard manure can be applied in soil during second weeding to get better yield from the first year itself. Fencing is essential to protect the crop from browsing and grazing

### Harvesting and ratooning

Brooms (inflorescences) are harvested on maturity during winter season from January to March. The panicles become tough and its colour changes to light green or red. The harvesting should be done carefully when the brooms have matured properly. The culms are harvested by cutting above the ground, panicles and stem are disjoined. The panicles can also be hand pulled and dried in fields. The woody stem (culms) can be used for fuel, fencing, pulp and paper or other purposes. Young and newly sprouted shoots should not be damaged during the harvest. Brooms are made by bundling about 30-35 dried inflorescences and sold in the market. It is not a perishable product and can be stored or transported to distant places. The leaves are harvested for fodder once in the middle of monsoon (August) from second year onwards. The ratoon of this grass can be taken up to 5<sup>th</sup> or 6<sup>th</sup> year of planting.



**Table 1. Yield of Broom Grass during 2021-2024**

Sl.N o.	Yield	1 <sup>st</sup> year (2021)	2 <sup>nd</sup> year (2022)	3 <sup>rd</sup> year (2023)	4 <sup>th</sup> year (2024)
1	Av. Yield of culms/tuss	14	57	185	165



	ock				
2	Total yield of culms (from 2500 tussocks)	35,000	142,500	462,500	412,500
3	Total No. of brooms (Av. 35 sticks/broom)	1000	4071	13,214	11,785
4	Total income @ (Rs. 50 per broom)	50,000	203,500	660,700	589,250

### Yield and Economics of broom grass cultivation

The yield is low in first and fifth year. The highest yield is obtained in the third year. The maximum growth takes place from 2nd year onwards when annual increment in number of culms per tussock is very high. The yield of broom mainly depends upon the quality of planting material, type of land and cultural practices adopted. Broom grass cultivation can be a good profitable enterprise. This information gives a general idea about the economics of cultivation and can be helpful to the farmers and other growers who intends to take up its plantation as a cash crop. However, it varies according to labour efficiency, wages, soil fertility, cultural practices, market price and demand, etc. The profit can be raised further if brooms (final saleable product) are processed by the cultivator themselves. The planting and establishment costs can be saved to great extent if the individual/farmer and his family members take up the works themselves. The value of the fodder, fuel wood, etc. has not been added in this calculation. The yield obtained in the abandoned jhumland at Churachandpur District is given in Table 1.

### Ecological benefits of broom grass cultivation in the jhum fallow:

Cultivating broom grass in jhum fallows offers significant ecological benefits by stabilizing soil, reducing erosion on degraded slopes, improving nutrient cycling, and enhancing land productivity, acting as a sustainable alternative to prolonged fallow periods, all while providing economic returns and fodder/fuel for local communities. Its robust root system binds soil, preventing runoff, while its biomass enriches soil organic matter and structure, making it a key tool for rehabilitating land degraded by shifting cultivation.

- **Soil Stabilization & Erosion Control:** The strong, web-like roots of broom grass effectively bind the soil, drastically reducing water runoff and soil loss, especially on steep jhum fallows.
- **Land Reclamation:** It thrives on degraded land, stabilizing it and preventing further environmental damage, turning unproductive areas into useful resources.
- **Improved Soil Health:** Intercropping with trees (agroforestry) or its own leaf litter improves soil organic matter, nutrient cycling, and overall soil physical structure, benefiting the entire ecosystem.
- **Reduced Fallow Period:** By cultivating broom grass, farmers can shorten the traditional fallow cycle, using the land productively for economic returns while still achieving land rehabilitation.
- **Biodiversity Support (Agroforestry):** When grown with other crops or trees, it creates diverse microclimates and enhances resource use efficiency (water, nutrients, sunlight).

### Livelihood improvement and economic benefits of broom grass cultivation:

Cultivation of broom grass significantly improves the rural livelihood by providing a sustainable and high value cash crop with multiple uses, requiring



minimal investment and labor. It also offers a steady source of income for the jhumias particularly during the lean seasons.

- **High Profitability:** Broom grass provides a cash return 8 to 10 times greater than traditional crops like rice and pulses with minimal investment.
- **Low Investment & Maintenance:** The crop requires minimal initial investment and maintenance after the first year, making it an accessible option for resource-poor farmers
- **Long-Term Income:** Once planted, broom grass can provide profitable yields for up to 10-15 years, ensuring a long-term, stable income source reducing the need for the frequent shifting of cultivation plots (jhum cycle).
- **Market Demand:** There is a large and consistent demand for the mature inflorescence used for making durable brooms in the markets

- **Employment Generation:** The cultivation process, including harvesting and processing into brooms, is labour-intensive and creates local employment opportunities for both men and women, particularly during the harvesting season (January to March).

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# Biofloc Technology as an Integrated Aquaculture– Agriculture System for Sustainable Farming

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## Introduction

Aquaculture has emerged as one of the fastest-growing food production sectors worldwide and plays a critical role in ensuring food security, nutritional stability, and livelihood support, particularly in developing countries. Fish and shrimp farming provide high-quality animal protein and regular income to millions of rural households. However, conventional aquaculture practices are increasingly constrained by high water requirements, frequent water exchange, escalating feed costs, nutrient loss, and environmental pollution. Discharge of untreated effluents rich in nitrogen and phosphorus often leads to eutrophication of natural water bodies and deterioration of surrounding agricultural soils.

Parallely, modern agriculture faces its own set of challenges, including rising fertilizer prices, declining soil fertility, depletion of organic matter, water scarcity, and climate-induced uncertainties. The need for sustainable, resource-efficient, and climate-resilient farming systems has therefore become more urgent than ever. In this context, Biofloc Technology (BFT) has gained global attention as an innovative approach that not only improves aquaculture productivity but also creates a strong functional linkage with agriculture through nutrient recycling and efficient resource utilization.

## 1.1 Concept and Definition of Biofloc Technology

Biofloc Technology is an advanced aquaculture system that operates on the principle of in situ waste nutrient conversion. In biofloc systems, nitrogenous wastes primarily ammonia excreted by cultured fish and shrimp are biologically transformed into microbial biomass by manipulating the carbon-to-nitrogen (C:N) ratio of the culture water. The resulting microbial aggregates, known as bioflocs, consist of beneficial heterotrophic bacteria, autotrophic algae, protozoa, fungi, and organic detritus suspended in the water column.

Unlike conventional systems where waste is removed through water exchange, biofloc systems retain and reutilize nutrients within the culture environment. This approach converts waste into a valuable resource, thereby improving water quality, enhancing productivity, and reducing environmental impact.

## 1.2 Working Principle of Biofloc Technology

The functioning of biofloc technology is primarily based on promoting the growth of heterotrophic bacteria through external carbon supplementation. Fish and shrimp feeds contain high protein levels, and only a portion of this protein is converted into animal biomass; the remaining nitrogen is released into the water as ammonia. In biofloc systems, carbon sources such as molasses, jaggery, rice bran, wheat flour, or tapioca powder are



added to maintain an optimal C:N ratio, generally between 12:1 and 20:1.

This carbon enrichment stimulates rapid bacterial growth, allowing heterotrophic microbes to assimilate ammonia and convert it into microbial protein. Continuous and vigorous aeration is essential to keep the bioflocs suspended, ensure adequate dissolved oxygen levels, and facilitate efficient microbial activity. Over time, a stable microbial community develops, creating a self-regulating system with minimal or zero water exchange.

### 1.3 Advantages of Biofloc-Based Aquaculture

Biofloc technology offers several advantages over traditional aquaculture systems. It significantly reduces water consumption, making it suitable for water-scarce regions. The conversion of toxic nitrogenous wastes into microbial biomass improves water quality and reduces stress on cultured organisms. Bioflocs act as a natural supplementary feed rich in protein, lipids, vitamins, and minerals, thereby improving feed conversion efficiency and reducing feed costs by 20–30 percent.

Additionally, biofloc systems enhance biosecurity by limiting water exchange and reducing the entry of pathogens. The dominance of beneficial microbial populations suppresses harmful bacteria through competitive exclusion, lowering disease incidence and reducing the need for antibiotics and chemicals. These features make biofloc farming environmentally sustainable, economically viable, and socially acceptable.

## 2. Integration of Biofloc Technology with Agriculture

The most distinctive and impactful feature of biofloc technology is its potential for integration with agriculture. At the end of a culture cycle, biofloc water contains high concentrations of organic matter and essential plant nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, and trace elements. Instead of being discharged as waste,

this nutrient-rich water can be reused for irrigating agricultural crops, vegetable fields, orchards, and fodder crops.

Application of biofloc water enhances soil microbial activity, improves soil structure, increases organic carbon content, and promotes better nutrient availability. This practice reduces dependence on chemical fertilizers, lowers input costs, and contributes to long-term soil health.

Agricultural by-products such as rice bran, wheat bran, broken grains, and oil cakes can be recycled as carbon sources in biofloc systems, creating a mutually beneficial exchange between aquaculture and agriculture. This circular nutrient flow minimizes waste, maximizes resource efficiency, and strengthens farm sustainability.

### 2.1 Biofloc Systems in Integrated Farming Models

Biofloc technology fits seamlessly into integrated farming systems where multiple enterprises support each other. Fish or shrimp culture provides nutrient-rich water for crop production, while crop residues and by-products support biofloc microbial growth. Such integration diversifies income sources, enhances farm resilience, and provides year-round employment opportunities.

Integrated biofloc farming systems are particularly beneficial for small and marginal farmers, as they optimize land and water use while reducing production risks. Even under adverse climatic or market conditions affecting crops, income from aquaculture provides economic stability, thereby strengthening rural livelihoods.

## 3. Water Conservation and Climate Resilience

One of the most significant advantages of biofloc technology is its minimal water requirement. Since water exchange is negligible, the same water can be reused for multiple culture cycles and later diverted for agricultural irrigation.



By conserving water, recycling nutrients, and reducing greenhouse gas emissions associated with fertilizer production and effluent discharge, biofloc-based integrated farming systems contribute to climate-smart agriculture and aquaculture practices.

#### 4. Economic Viability and Cost Economics

##### A. Capital Cost (One-Time Investment)

Sl. No.	Item	Specification / Quantity	Unit Price (Rs.)	Total Cost (Rs.)
1	Biofloc tank (HDPE/Tarpaulin)	10,000 L – 1 No.	65,000	65,000
2	Tank frame & foundation	Lump sum	—	10,000
3	Air blower	1 HP – 1 No.	22,000	22,000
4	Air pipes & valves	Complete set	—	6,000
5	Air stones/diffusers	10 Nos.	300	3,000
6	Electrical fittings	Lump sum	—	4,000
7	Water quality test kit	1 Set	10,000	10,000
8	Accessories (nets, buckets, Imhoff cone)	Lump sum	—	5,000
	<b>Total Capital Cost</b>			<b>1,25,000</b>

##### B. Operational Cost per Culture Cycle

	Component	Cost (Rs.)
i	Seed	10,000
ii	Feed	45,600
iii	Carbon sources	5,200
iv	Probiotics & conditioning	3,175
v	Electricity & labour	14,000
vi	Miscellaneous	2,000
	<b>Total Operational Cost</b>	<b>79,975 (~80,000)</b>

##### i. Seed Cost

Item	Quantity	Unit Price (Rs.)	Total Cost (Rs.)
Fish seed	2,500 Nos.	4	10,000

##### ii. Feed Cost

Item	Quantity (kg)	Unit Price (Rs./kg)	Total Cost (Rs.)
Floating pellet feed	1,200	38	45,600

##### iii. Carbon Source Cost

Item	Quantity (kg)	Unit Price (Rs./kg)	Total Cost (Rs.)
Molasses / jaggery	120	30	3,600
Rice bran / wheat flour	80	20	1,600
<b>Total Carbon Cost</b>			<b>5,200</b>



*iv. Probiotics & Water Conditioning*

Item	Quantity	Unit Price (Rs)	Total Cost (Rs)
Biofloc probiotic	3 kg	800/kg	2,400
Lime alkalinity buffer	20 kg	20/kg	400
Salt	25 kg	15/kg	375
Total			3,175

*v. Electricity & Labour*

Item	Quantity / Duration	Cost (Rs)
Electricity	~600 units	6,000
Labour (part-time)	5 months	8,000
Total		14,000

*vi. Miscellaneous Expenses*

Item	Cost (Rs)
Nets, medicines, minor repairs	2,000

**C. Production and Returns from Aquaculture**

Parameter	Value
Total biomass harvested	1,600–1,800 kg
Average market price	Rs. 150/kg
Gross income	Rs. 2,40,000–2,70,000

**D. Net Profit from Biofloc Aquaculture**

Description	Amount (Rs.)
Gross income (average)	2,55,000
Total operational cost	80,000
Net profit per cycle	1,75,000

**E. Additional Economic Benefits from Agriculture (Integration)**

Benefit	Estimated Value (Rs.)
Saving on chemical fertilizers	10,000–15,000
Increased crop yield	15,000–25,000
Total agricultural benefit	25,000–40,000

**F. Overall Profitability of Integrated System**

Component	Amount (Rs.)
Net profit from aquaculture	1,75,000
Agricultural benefit	15,000–25,000
Total net benefit per cycle	Rs. 1.90–2.00 lakh

The tabulated cost economics clearly demonstrate that a biofloc-based integrated aquaculture–agriculture system is **highly profitable and economically sustainable**. Moderate capital investment, rapid capital recovery within 1–2 cycles, reduced feed and fertilizer costs, efficient water reuse, and enhanced crop productivity make biofloc technology an ideal model for small, medium, and commercial farmers.

**5. Environmental and Social Benefits**

Biofloc technology significantly reduces nutrient discharge into natural water bodies, prevents eutrophication, improves soil health, and promotes sustainable resource use. Reduced chemical input enhances environmental safety and consumer confidence. Socially, biofloc-based integrated farming generates employment, improves income stability, enhances food and nutritional security, and supports sustainable rural development.

**6. Conclusion**

Biofloc technology represents a paradigm shift in modern aquaculture by transforming waste into



wealth and linking aquaculture seamlessly with agriculture. Through efficient nutrient recycling, water conservation, reduced pollution, and enhanced productivity, biofloc-based integrated farming systems offer a sustainable solution to the challenges faced by both sectors. With appropriate training, scientific management, and institutional support, biofloc technology has the potential to become a cornerstone of future agriculture–aquaculture integration, ensuring economic viability, environmental sustainability, and improved livelihoods for farming communities.

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# Agro-Homeopathy: A Novel Approach For Managing Insect Pests in Agriculture

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Insect pest in agriculture causes significant damage to the crops and thus reduces the overall income of farmers. Several synthetic based insecticides have played a significant role in controlling this pest but their toxic residues have created lots of ecological imbalances. In search of alternatives, homeopathic medicines have emerged as an option as these medicines at minute quantities can causes larval mortality in several insects. In recent days, concept of agro-homeopathy has gained major attention among scientific communities to conduct more research to check the efficacy of different homeopathic medicines at different concentrations against insect pests. In future, there is a need to standardize the dose of these medicines as agricultural pesticides to implement it in the organic management modules.

## Introduction

Management of insect pest in agriculture now a days have become a major concern among the farming communities as due to climate change and development of pesticide resistance have causes significant raise in the population of insect pest in agriculture. Due to this, huge crop loss can be seen every year and thus it reduces farmers income generation. Use of synthetic insecticides have played a major role in managing this pest but their toxic residues can persist in the environment for longer period. Due to this, it has created poor soil health, crop health and also causes ecological imbalances. The toxic residue of this pesticides can also impart negative effect on the non-targeted beneficial insects. In search of alternatives to these chemicals, use of organic based amendments have shown prominent result in managing this biotics stresses. Use of microbial based inoculants or entomopathogens also have played a significant role in reducing the pest population below economic threshold level (Dutta *et al.*, 2023). Beside this practices, recent studies on use of homeopathic medicines for overall plant health management purpose where these remedies also have shown effective against plant pathogens and insect pests. These medicines are mainly prepared from plant parts and other organic derivatives where at

minute doses it shows growth inhibitory effect on agricultural pests. Although, there were very less report on the use of homeopathic medicines against insect pest has been reported till date but many researchers and farmers are now a days shifting towards agro-homeopathic concept as these medicines have wide range of plant growth promoting properties and anti-microbial and insecticidal properties.

**Agro-homeopathy:** It is a branch of homeopathic science, where these medicines are use in the field of agricultural purposes. Initially these remedies were used to check its efficacy on germination of seeds. Later these medicines were found that it can also promote overall plant growth and development. With growing interest among the researchers and the framing communities on the use of these medicines on plants, several studies were conducted across the world to check its effectiveness on management of agricultural pests. These medicines were tested at different doses against microbial pathogens and insect pests and their most effective doses were identified. As these medicines are chemical less and nontoxic in nature, therefore these remedies can be implemented in the agricultural sector.



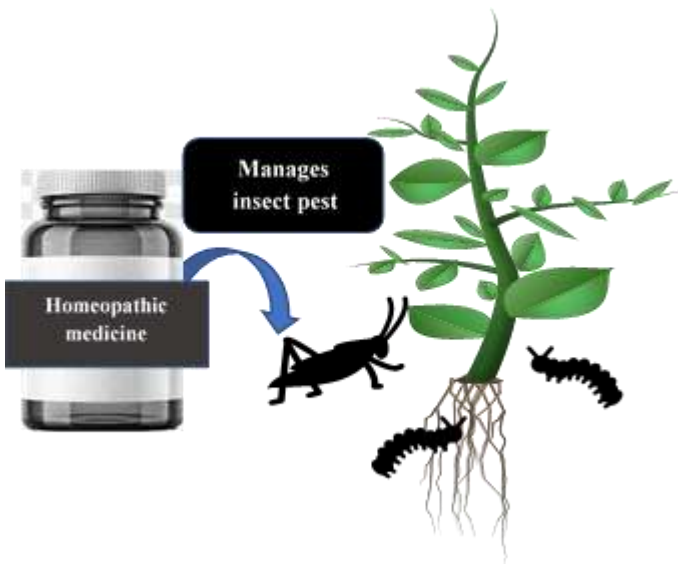


Fig 1: Homeopathic medicines against insect pest

**Homeopathic medicines used for managing insect pest in agriculture:**

Although there were very few studies has been conducted on the use of homeopathic medicines against insect pest but some of the medicines were reported to have insecticidal properties. Wanis *et al.*, (2010) reported that Rigorous a homeopathic medicine has showed insecticidal property against wheat aphid and have enhances the production of this crop. Rigorous @1.5% solution along with 100 L of water per acre revealed less infestation of aphids as compared to pre-treatment and showed less detrimental to the natural enemies. Silva *et al.*, (2023) studied the role of homeopathic medicine for

managing velvet bean caterpillar. The result highlighted that, homeopathic medicines can alter the biological aspects of *Anticarsia gemmatalis* and also reduce the feed efficiency of this insect pest. Almadani and Hiware (2020) stated that homeopathic drug such as Iodium can increase the mortality rate of greater wax moth larva i.e. *Galleria mellonella* L. with increase in the concentration of this drug. Sulphur a homeopathic medicine was found to be effective against scale insects. In another study by Kaviraj (2020) have reported that, homeopathic medicines like Lycopodium clavatum 15C and aphid nosode 6C were found to be effective against apple aphids where it has reduced its population by 17% and 14% respectively. The shoot and fruit borer of egg plant i.e. *Leucinodes orbonalis* is considered as one of the major insect pests of this crop. Homeopathic medicines like *Thuja occidentalis* 200C was found to be effective against this insect pest of egg plant (Prasad and Varma, 2024). Recent studies also have found that, homeopathic medicine i.e. *Sulphur* 12 CH was found to be promising in managing tomato fruits from small borer infestation (Modolom *et al.*, 2012). Therefore, in support of these studies homeopathic medicines can be used for managing insect pest of agricultural crops but their efficacy at different doses are need to be studied against different insect pest groups at different agro-ecological conditions. Details of this studies and findings are highlighted in table 1.

**Table1:** List of some homeopathic medicines and its effectiveness against targeted insect pests.

Sl. No.	Homeopathic Medicine	Potency / Dose	Target Insect Pest	Crop	Major Findings	Author(s) & Year
1	Rigorous	1.5% solution (100 L water/acre)	Wheat aphid	Wheat	Reduced aphid infestation; enhanced crop production; less harmful to natural enemies	Wanis <i>et al.</i> , 2010



2	Homeopathic formulations (not specified)		<i>Anticarsia gemmatalis</i> (Velvet bean caterpillar)	Soybean	Altered biological parameters; reduced feeding efficiency	Silva <i>et al.</i> , 2023
3	<i>Iodium</i>	Increasing concentrations	<i>Galleria mellonella</i> L. (Greater wax moth larva)	Laboratory study	Increased larval mortality with higher concentration	Almadani & Hiware, 2020
4	<i>Sulphur</i>	Not specified	Scale insects	Not specified	Effective in managing scale insect infestation	
5	<i>Lycopodium clavatum</i> 15C	15C potency	Apple aphid	Apple	Reduced aphid population by 17%	Kaviraj, 2020
6	<i>Aphid nosode</i> 6C	6C potency	Apple aphid	Apple	Reduced aphid population by 14%	Kaviraj, 2020
7	<i>Thuja occidentalis</i> 200C	200C potency	<i>Leucinodes orbonalis</i> (Shoot and fruit borer)	Eggplant (Brinjal)	Effective in managing infestation	Prasad and Varma, 2024
8	<i>Sulphur</i> 12 CH	12 CH potency	Small fruit borer	Tomato	Promising in reducing fruit infestation	Modolom <i>et al.</i> , 2012

**Challenges:** Although recent studies have proven the insecticidal property of homeopathic medicines but their standard dose are need to be evaluated in the future endeavours. The efficacy of homeopathic medicines against several insect pest at different agroecological conditions are need to be evaluate. The effect of these remedies on non-targeted organisms should be taken into considerations under future line of works related to agro-homeopathy.

**Benefits of using homeopathic medicines for pest management:**

**Boosts plant health:** Homeopathic medicines can promote the plant growth and development and

triggers the production of plant secondary metabolites; these secondary metabolites helps in defence mechanism against insect pests and pathogens.

**Eco friendly:** Most of the homeopathic medicines are derived from plant parts so it do not leaves any toxic residues in the soil unlike chemical pesticides.

**Economic and practical gains:** Low cost and their use at minute quantities makes these remedies as cost effective for farmers. Their application as foliar spray and seed treatment requires less manpower for its application in the field.



**Challenges and future prospects:**

Although there is a huge potential benefit homeopathic medicines in agriculture but still it faces several challenges like lack of clear scientific explanations and its mechanism and proper mode of action. Contamination of homeopathic medicines with other pesticides can alter its own properties and which may lead to non-effectiveness in several cases.

The future of homeopathy in insect pest management depends on advancing the research and technology. With advancement, homeopathy could become a more widely accepted tool in sustainable agriculture.

**Conclusion:**

In conclusion, homeopathy offers a promising approach to plant disease management that aligns with the principles of sustainability and holistic farming. While challenges and controversies exist, the potential benefits for the environment, economics, and crop health make it a valuable area of exploration. As research and awareness grow, homeopathy may become an increasingly important tool in the quest for sustainable agriculture and resilient farming systems.

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# Role of Technology Gap in Sugarcane Production: Implications for Productivity and Sustainability

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Sugarcane is a major commercial crop contributing significantly to rural livelihoods, sugar industries, and bioenergy production. Despite technological advancements, sugarcane productivity in many regions remains below potential levels due to technology gaps between recommended scientific practices and farmer's field adoption. This paper reviews the concept of technology gap in sugarcane cultivation, major areas of adoption constraints, causes influencing technology dissemination, and strategies to improve productivity. Evidence from extension studies and yield gap analyses indicates that poor adoption of improved varieties, irrigation methods, balanced fertilization, and plant protection practices contributes significantly to reduced yield and economic efficiency. Bridging the technology gap through effective extension services, training, improved infrastructure, and policy support is essential to enhance sustainable sugarcane production.

## Introduction

A significant cash crop that is extensively grown in tropical and subtropical areas, especially in India, is sugarcane (*Saccharum officinarum L.*). It provides a living for millions of farmers and is used as a raw material for bioproducts, ethanol, sugar, and jaggery. Despite the availability of contemporary agronomic methods and better varieties, farmers' actual productivity is frequently far lower than the potential yield. The main causes of the variation are adoption barriers in agricultural management techniques and technological disparities. Research has shown that increasing productivity and resource efficiency in sugarcane farming requires better extension assistance and the display of cutting-edge technologies.

## Concept of Technology Gap

The variation between the actual yield that farmers get and the potential yield under suggested scientific management is known as the "technology gap." Studies on sugarcane yield gaps have revealed that a

major factor in productivity disparities is the limited adoption of modern technology and conventional growing methods.

Gaps in technology can result from: Refusal to use improved varieties, Ineffective nutrient management and irrigation, Limited information transfer from research to the field, inadequate pest and disease management, and a lack of automation.

## Major Areas of Technology Gap in Sugarcane Cultivation

The selection of better varieties is one of the primary areas where there is a technical gap. High-yielding, disease-resistant, and climate-tolerant sugarcane cultivars are frequently released by agricultural colleges and research centers. However, due to ignorance or a lack of access to high-quality seed, many farmers still produce outdated or traditional types. The crop produces less yield and sugar recovery as a result, and it becomes more vulnerable to pests and illnesses. Although adopting better varieties that are peculiar to a certain location might



significantly boost production, many places have yet to completely exploit this technology.

Another major gap exists in seed and planting practices. To achieve a uniform crop stand, scientists advise using healthy, disease-free setts, proper sett treatment methods and spacing with adequate spacing. Improved germination and resource efficiency are achieved through techniques like trench planting, paired row planting and bud chip technology. Despite this, numerous farmers continue with traditional flat planting without sett treatment, which results in poor germination and weak plant growth. A shortage of skilled workers and ignorance of modern planting methods are also contributing factors to this gap.

Another critical area of technology gaps is in nutrition management. A heavy feeder crop, sugarcane is rich in nitrogen and phosphorus as well as potassium and micronutrients such as zinc and iron. The use of soil testing and site-specific nutrient management is advised to enhance soil fertility and crop growth. Often, farmers apply too much nitrogen without considering the benefits of micronutrients or organic manure, which can lead to nutritional deficits, soil erosion, and lower yields. Fertilizers are often used improperly because of limited access to soil testing facilities and awareness.

The deficiency in irrigation and water management also impacts the yield of sugarcane. By utilizing efficient irrigation techniques like drip irrigation and fertigation, water can be conserved and yields increased. Nevertheless, the use of traditional flood irrigation persists, leading to water wastage, inadequate nutrition through leaching, and occasional waterlogging. The high initial cost, lack of training, and financial constraints of drip systems make it difficult for farmers to adopt modern irrigation technologies.

Another sector that has not completely embraced enhanced technologies is weed management. Using prescribed herbicides, mulching, and timely

intercultivation are examples of scientific practices. Because of labor shortages or high labor costs, farmers frequently rely on hand weeding, which might be delayed. Weeds therefore compete with the crop for moisture and nutrients, which eventually lowers output. The technical gap is further widened by incorrect application.

There is also a significant gap in pest and disease management. Sugarcane is affected by pests like early shoot borer, top borer, and diseases such as red rot and smut. Integrated Pest Management (IPM) practices, including resistant varieties, biological control agents, and timely chemical application, are recommended. However, many farmers rely on excessive or untimely pesticide use without proper diagnosis, which increases production costs and reduces effectiveness. Limited extension services and inadequate training contribute to poor adoption of IPM practices.

### **Causes of Technology Gap in Sugarcane Production**

Various socio-economic and institutional factors contribute to the technology gaps in sugarcane farming, such as inadequate farmer awareness and training, limited demonstrations and poor extension services, high input costs and financial constraints, labor shortages, lack of infrastructure, inadequate irrigation facilities, and resistance to new technologies caused by traditional practices.

Research indicates that technology adoption rates among sugarcane growers are significantly influenced by factors such as high input prices, labor shortages, and climatic variability.

### **Impact of Technology Gap on Productivity**

Technology gap result in lower yields, diminished sugar recovery, and ineffective usage of water and fertilizers. Research in extension has demonstrated that the adoption of advanced technologies can greatly enhance yield in comparison to conventional



farming methods, highlighting the significance of technology transfer and uptake.

Moreover, stagnant productivity in specific areas has been associated with inadequate adoption of contemporary agronomic practices and restricted access to high-quality inputs.

### Strategies to Reduce Technology Gap

Reducing the technology gap requires a combination of awareness, access, skill development and continuous support to farmers.

Initially, enhancing extension services and the activities of Krishi Vigyan Kendras (KVKs) enables farmers to grasp new technologies via demonstrations, field days, and training programs for farmers.

Secondly, enhancing access to high-quality resources, credit options, and affordable equipment allows farmers to implement better practices without incurring financial strain.

Third, encouraging digital literacy and the utilization of mobile advisory services can deliver prompt information regarding weather conditions, pest control, and market prices.

Fourth, promoting cooperative learning and farmer producer organizations (FPOs) facilitates the

exchange of successful inventions and experiences among farmers.

At the final , consistent observation, input, and site-specific study guarantee that technologies are useful, affordable, and appropriate for regional circumstances, thereby narrowing the discrepancy between suggested practices and real field implementation.

### Conclusion

The technology gap continues to be a key factor restraining sugarcane productivity in numerous areas. Closing this gap necessitates collaborative initiatives among research institutions, extension services, policymakers, and farmers. The implementation of superior varieties, effective irrigation techniques, proper fertilization, and mechanization can greatly improve both productivity and sustainability. Ongoing education for farmers, development of infrastructure, and enhanced technology sharing systems are crucial for achieving the maximum yield potential in sugarcane cultivation.

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# Reclaiming the Earth: How Mined Lands Are Brought Back to Life

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Mining plays a crucial role in supporting modern life, but it also leaves behind disturbed landscapes in the form of overburden (OB) dumps and excavated areas. These dumps, if left untreated, can lead to soil erosion, dust pollution, slope instability and loss of biodiversity. Fortunately, through a combination of technical and biological reclamation methods, these barren mounds can be transformed into stable, green and productive ecosystems. This process of reclamation is not just about beautification it is about restoring ecological balance, preventing environmental degradation, and creating sustainable landscapes for future generations.

## Technical reclamation

Technical reclamation is the engineering phase that prepares an overburden (OB) dump for ecological restoration. It involves reshaping the dump through leveling, grading, and terracing to reduce slope steepness and control runoff velocity. Proper drainage systems such as top surface drains and garland drains are constructed to safely channel rainwater and prevent seepage that could weaken slopes. Measures like gully plugging and check dams are installed to control erosion and arrest silt movement. Geo-synthetic or biodegradable jute mats are laid for early slope stabilization, and gabion retaining walls provide additional mechanical support where required. A crucial component of this stage is the preservation and spreading of stored topsoil over the dump surface, ensuring that the reclaimed land has a fertile base for future plantation.

## Biological reclamation

Once structural stability is achieved, biological reclamation begins to restore vegetation and ecological balance. Grass seeds are broadcast either manually or using hydro-seeders especially before the monsoon, so they germinate early and prevent soil erosion. After initial stabilization by grasses, indigenous tree saplings are planted on flat areas and

terraced slopes, and sometimes even on steeper gradients. A multi-species plantation approach is encouraged, combining timber, fruit-bearing, medicinal, and aromatic plants to enhance biodiversity and long-term sustainability. Bio-fertilizers and, where permitted, fly ash may be applied to improve soil fertility. Over time, this vegetation cover binds the soil, improves soil health, reduces pollution, and transforms barren dumps into productive green landscapes

## Power of Multi-species plantation

Mixed-species plantations are preferred over monoculture because they more closely resemble natural forest ecosystems and are therefore more stable and self-sustaining. In monoculture plantations, a single species is planted over a large area, which makes the ecosystem vulnerable to pests, diseases, and climatic stress. If one species fails, the entire plantation may suffer. In contrast, a heterogeneous mix of timber species (such as teak or sal), fruit-bearing trees (like mango or aonla), medicinal and aromatic plants, along with grasses and shrubs, creates structural and functional diversity. Different species have varying root depths, canopy structures, and nutrient requirements, allowing them to utilize soil, sunlight, and moisture



more efficiently without intense competition. It also enhance biodiversity by providing varied habitats and food sources for birds, insects, and small animals, thereby accelerating ecological succession. Grasses help in immediate soil binding, shrubs offer intermediate cover, and taller trees provide long-term canopy development. This layered vegetation improves soil fertility through leaf litter addition and microbial activity, increasing organic matter over time. Economically, such plantations generate multiple outputs—timber, fruits, fodder, medicinal products, and non-timber forest produce—benefiting local communities. Environmentally, they improve carbon sequestration, reduce erosion, stabilize slopes, and create resilient green belts capable of withstanding environmental stresses, ensuring sustainable restoration of reclaimed mining areas.

**Suitable tree species for plantation**

Tamarind ( <i>Tamarindus indica</i> )	Teak ( <i>Tectona grandis</i> )
Khair ( <i>Acacia catechu</i> )	Bamboo ( <i>Bambusa arundinacea</i> )
Neem ( <i>Azadirachta indica</i> )	Babul ( <i>Acacia nilotica</i> )
Aonla ( <i>Phyllanthus emblica</i> )	Ber ( <i>Ziziphus mauritiana</i> )
Mango ( <i>Mangifera indica</i> )	Palas ( <i>Butea monosperma</i> )
Bijasal ( <i>Pterocarpus marsupium</i> )	Kusum ( <i>Schleichera oleosa</i> )

**Reclamation efforts also extend to**

- ❖ Backfilled internal dump areas
- ❖ Vacant lands as mitigation measures
- ❖ Avenue plantations and green belts to reduce air and noise pollution

Green belts around mining zones act as environmental shields, improving air quality and reducing dust dispersion.

**Conclusion**

Land reclamation is a powerful example of how science, engineering and ecology can work together to repair environmental damage. What begins as a barren overburden dump can, through careful planning and sustained effort, become a thriving green landscape.

Technical stabilization ensures safety and durability, while biological reclamation restores life and ecological balance. With multi-species plantations and sustainable soil management practices, reclaimed mining lands can serve communities, support biodiversity, and stand as living proof that environmental restoration is both possible and practical.



# Precision Pest Management Using AI & Drones

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Precision Pest Management (PPM) is a smart and practical approach to controlling crop pests by using accurate information and timely action. Instead of spraying the entire field as a routine practice, PPM focuses on treating only the areas where pests are actually present. It depends on field observations, digital tools, and modern technologies to detect problems early and respond in a precise manner. With the help of artificial intelligence, remote sensing, drones, and decision-support systems, farmers can closely monitor crop health and quickly identify pest hotspots. This allows them to apply pesticides or other control measures only where needed. As a result, chemical use is reduced, production costs are lowered, and environmental damage is minimized, while still maintaining effective pest control and good crop yield. Advanced image analysis and forecasting models also help predict pest outbreaks before they become severe. This early warning system enables farmers to take preventive measures and avoid heavy crop losses. Drones further support this process by improving field surveillance and ensuring accurate application of pesticides, biopesticides, or biological control agents. By strengthening the principles of Integrated Pest Management (IPM), PPM encourages sustainable farming practices. It reduces unnecessary pesticide use, protects beneficial insects, and promotes informed decision-making based on real-time data. Although challenges such as high initial investment, lack of technical knowledge, and regulatory concerns may limit its adoption in some areas, improved access to digital tools and better farmer training are gradually overcoming these barriers. Overall, Precision Pest Management provides a balanced and responsible approach to crop protection, combining technology and practical field knowledge to achieve both economic and environmental sustainability.

## Introduction

Precision Pest Management (PPM) is a practical and knowledge-based approach to controlling crop pests. It focuses on applying the right treatment, at the right place, and at the right time, in the correct amount. By combining modern digital technologies with the basic principles of Integrated Pest Management (IPM), PPM helps reduce unnecessary chemical use, lower farming costs, and minimize harm to the environment, while still maintaining effective pest control and improving crop yield.

Unlike traditional methods that treat the entire field uniformly, Precision Pest Management concentrates only on areas where pests are actually present. It relies on real-time field observations, digital tools, and smart technologies to guide decisions. With the support of AI-based analysis and drone monitoring,

farmers can detect early signs of infestation, identify affected zones, and apply treatments accurately.

This focused approach saves time, money, and resources. At the same time, it protects crop health and preserves beneficial organisms in the surrounding ecosystem. Overall, Precision Pest Management offers a balanced and efficient way to manage pests while promoting sustainable agriculture.

## Integrated Tools for Smart and Sustainable Pest Control

### Precision Monitoring

It employs technologies such as pheromone-based traps, satellite imagery, unmanned aerial vehicles (drones), intelligent sensors, and AI-assisted imaging systems to enable early and accurate detection of pest



incidence. Drones equipped with multispectral cameras and AI detect pests early by mapping stressed crop areas with 90% accuracy. In India, they cover 50 acres daily, enabling targeted interventions over blanket spraying. Acoustic sensors and GIS track insect populations in real-time, predicting outbreaks via apps like ICAR's PESTPREDICT. This data-driven approach saves 30-40% on inputs, aligning with SDG (Sustainable Development Goals). Satellite and drone integration under NICRA help climate-vulnerable regions to adapt and reduce losses from migratory pests.

### Biological and Environment-friendly Approaches

It Promotes the strategic release of beneficial organisms such as predators and parasitoids, along with the use of biopesticides and mating disruption techniques, as alternatives to broad-spectrum chemical applications. AI-driven apps and acoustic sensors detect pest sounds or vibrations, predicting outbreaks via machine learning models trained on vast datasets. ICAR-NCIPM's PESTPREDICT app, for instance, issues location-specific alerts for rice pests, integrating weather data for proactive IPM.

Pheromone traps paired with IoT sensors provide real-time population data, triggering automated responses like drone sprays. These tools enhance SDG 9 (Industry, Innovation, and Infrastructure) by democratizing tech for resource-poor farmers, while cutting chemical loads to aid SDG 6 (Clean Water and Sanitation). Trials in Tamil Nadu show 25% fewer sprays needed, conserving water and energy.

### Major Drone applications

#### Aerial Crop inspection

Drones identify symptoms such as leaf discoloration, curling, and plant stress associated with insect attacks, reducing reliance on manual field checks.

#### Mapping Pest Hotspots

Drone imagery is transformed into detailed maps that pinpoint infestation zones, allowing farmers to concentrate treatments only where needed.

#### Targeted Input Delivery

Advanced drones can precisely apply pesticides, biopesticides, or nutrients to affected patches, lowering chemical use, protecting beneficial organisms, and reducing labour costs.

In many locations, drones are also used to release biological control agents like Parasitoids, providing an eco-friendly alternative to chemical sprays.

Technology	Key Features	SDG Impact	Example
Drones	High-resolution imaging, GPS mapping	SDG 13, SDG 2	50 acres/day coverage, 30% chemical reduction
Sensors	Real-time pest detection	SDG 15	PESTPREDICT app for rice pests
GIS	Outbreak forecasting	SDG 12	NICRA risk maps

### Spatial Mapping

Utilizes GPS and GIS tools to generate detailed maps of pest occurrence, allowing identification of localized infestation zones and avoiding uniform treatment across entire fields

### Decision Support Systems (DSS)

Integrates pest surveillance data with weather parameters and crop growth stages to guide timely management decisions based on established Economic Threshold Levels (ETL).

### Targeted Application

Involves site-specific delivery methods including variable-rate spraying equipment, precision pesticide placement, and automated sprayers that focus treatment only on affected crop areas.



### Advancing sustainable agriculture

Precision pest management supports sustainable farming practices. Excessive pesticide use has led to resistance, residue issues, and biodiversity loss. AI and drone technologies strengthen Integrated Pest Management (IPM) by promoting:

- Location-specific chemical application
- Targeted release of beneficial insects
- Increased adoption of biopesticides
- Continuous monitoring and data-based decisions

### Real World Impacts and SDG Linkages

Innovation	Key SDG Advances	Benefits in India	Reduction in Chemicals
Drones & AI Monitoring	SDG 13, 9, 12	Early detection in rice/paddy; 50 acres/day coverage	30-50%
Entomopathogenic Biopesticides	SDG 2, 15, 3	Bt for cotton bollworm; Kerala spices	70-90% efficacy, no residues
IPM with Sensors	SDG 6, 12	PESTPREDICT app alerts	25% fewer sprays
Pollinator Conservation	SDG 15, 2	Wildflower strips in orchards	Enhanced yields 20-30%

### Barriers to adoption

Several challenges limit widespread adoption:

- High initial investment
- Limited technical awareness among growers
- Need for training and infrastructure
- Regulatory constraints on drone usage

### Overcoming Barriers to Widespread Use

Although precision technologies like drones and AI-based tools offer great promise, their adoption is not without practical difficulties. The cost of purchasing

drones, sensors, and related software can be high, especially for small and marginal farmers. In addition, many growers may not be familiar with operating such equipment or interpreting digital data. Without proper guidance, advanced tools may remain underutilized.

However, supportive government initiatives are gradually easing these challenges. Programs such as the Digital Agriculture Mission launched by the Ministry of Agriculture & Farmers Welfare and climate-resilience projects under NICRA (National Innovations in Climate Resilient Agriculture) are promoting the integration of digital tools into farming systems. These initiatives provide financial assistance, pilot demonstrations, and technical support that help farmers understand the practical benefits of precision technologies. By encouraging public-private partnerships and farmer-producer organizations, these programs are making modern pest management approaches more accessible at the grassroots level.

At the same time, collaborations between agri-tech start-ups, research institutions such as Indian Council of Agricultural Research, and non-governmental organizations are strengthening the production and distribution of eco-friendly inputs like biopesticides and biological control agents. In states like Kerala, small-scale production hubs and local enterprises are helping supply affordable biocontrol products tailored to regional crops. This localized approach not only reduces dependency on synthetic chemicals but also generates rural employment and strengthens community-level resilience.

Capacity building plays a crucial role in ensuring long-term success. Mobile-based advisory platforms, farmer field schools, village-level demonstrations, and hands-on drone training sessions are building confidence among farmers. When growers see visible reductions in pesticide costs, improved crop health, and better market acceptance due to lower residues, their willingness to adopt new methods increases.



The experience gained from conservation agriculture programs has already shown that when farmers are actively involved in learning and experimentation, adoption rates improve significantly.

Looking ahead, sustained investment in research and development remains essential. Emerging challenges such as pesticide resistance, invasive species, and climate-induced pest outbreaks require continuous innovation. Strengthening early warning systems, improving locally adaptable decision-support tools, and encouraging youth participation in digital agriculture can accelerate progress. With consistent policy backing, farmer education, and scientific advancement, precision pest management can move from being a promising innovation to a widely practiced reality, contributing meaningfully to food security, environmental protection, and the achievement of the Sustainable Development Goals.

### Conclusion

Precision Pest Management (PPM) marks an important shift from traditional, calendar-based pesticide spraying to a smarter and more informed way of protecting crops. Instead of applying chemicals at fixed intervals, farmers use tools such as artificial intelligence, drones, GIS mapping, sensors, and decision-support systems to understand exactly what is happening in their fields. These technologies help detect pest problems at an early stage, allowing farmers to take action only where it is truly needed. As a result, chemical use is reduced, production costs come down, environmental pollution is minimized, and beneficial organisms are protected.

When modern digital tools are combined with the principles of Integrated Pest Management (IPM), pest control becomes both efficient and environmentally responsible. Real-time pest forecasting, mapping of infestation hotspots, and drone-based targeted application make decisions more scientific and accurate. In addition, the use of biological control agents and biopesticides within

precision systems supports long-term resistance management and helps conserve biodiversity.

Although challenges such as high initial investment, limited technical knowledge, and regulatory concerns still restrict widespread adoption, growing government support, research collaborations, and farmer training programs are gradually making these technologies more accessible. As digital agriculture tools become more affordable and easier to use, Precision Pest Management is likely to play a key role in building climate-resilient and sustainable farming systems.

With increasing problems such as pesticide resistance, invasive pests, and climate change, PPM is not just an improvement in technology but a necessary step forward in crop protection. It offers a balanced approach that supports food security, protects the environment, and ensures economic stability for future generations.

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# Climate Change–Driven Shifts in Insect Pest Dynamics of the Rice-Wheat Cropping System in Western India

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The change in climate is now one of the primary factors of agricultural productivity due to its tendency to reorganize the biology, population levels, and distribution of insect pests. Western India has a food production system, the rice-wheat system, which is highly susceptible to temperature increases, unpredictable rainfall, and the slow but steady increase in CO<sub>2</sub> concentration in the atmosphere. Poikilothermic insects are sensitive to changes in climate- changing their rates of development, survivability, fecundity, voltinism and geographical distribution. The review summarizes available literature on the effect of climate change on the dynamics of insect pests in rice and wheat production. It focuses on the role of temperature, rainfall, and CO<sub>2</sub> in mediating pest biology, changing the crop-pest interaction, showing regional differences in pest outbreak, and also the implications of this on pest management. The paper identifies climate and smart pest management plans and indicates major research gaps. To come up with practical, sustainable and resilient pest-management strategies, it is important to understand these climate-pest interactions in the wake of changing climatic conditions.

## 1. Introduction

Climate change is increasing day by day which influencing to agricultural ecosystems by altering temperature ups and down, uncertain rainfall patterns, and atmospheric composition. These climatic changes have intense implications for insect pests, which are highly sensitive to environmental variation due to their very short life cycles and insect poikilothermic nature (Radwan *et al.*, 2024; Idigo *et al.*, 2025). Even small shifting in temperature and Precipitation, it can substantially modify insect development, their survival, voltinism of insect, and population growth of insects. (Radwan *et al.*, 2024; Abbas *et al.*, 2025). Moreover, warming temperatures are expected to increase the metabolic activity rates and also speedily increase their developments processes and increases population and damaging occurs (Burr *et al.*, 2025). It is Globally notice that similar trends have been

documented, highlighting climate change as a main key of emerging pest risks and agricultural losses (Carley *et al.*, 2025; Abbas *et al.* 2025).

Rice-wheat cropping is viewed as the food security backbone in western part India and it assists millions of smallholders in India. Global warming (which is expected to rise by 1.4-5.8 degrees Celsius before the end of this century) and CO<sub>2</sub> concentration in the atmosphere have already had an effect on the distribution, seasonal activity, and frequency of outbreak of pests (IPCC, 2001; Radwan *et al.*, 2024). The research on the Indian and global agro-climatic conditions suggests that irregularity of the monsoon behaviour, heat waves, and dry spells during the long time increase the number of pests and destabilize natural enemies synchrony in rice and wheat ecosystems (Radwan *et al.*, 2024; Abbas *et al.*, 2025). Multiple expansions in the range and greater number of generation per season have been seen in various



types of cropping systems across the globe (Carley et al., 2025; Burc et al., 2025). Increasing temperatures, aberrant precipitation, and high CO<sub>2</sub> levels in the atmosphere directly and indirectly affect the development, survival, reproduction, feeding, and pest-host relationships of insects (Abbas et al., 2025; Idigo et al., 2025). High CO<sub>2</sub> causes physiological changes in the plants, such as increase in carbon-to-nitrogen (C:N) ratio that in many cases may lead to poor nutritional quality of the plants and compensatory feeding by the herbivorous insects that may cause increased crop losses (Abbas et al., 2025). A rise in temperature can also reduce developmental time and extrinsic incubation of pathogens in the vectors, increasing the efficiency of transmission and pest pressure (Idigo et al., 2025). Also, it may lead to more rapid growth of pest populations and per capita feeding on hosts due to evolutionary adaptation to climate warming, which multiplies their agricultural footprint (Burc et al., 2025). Stresses of temperature and moisture in the field only speed up the accumulation of pest populations and the lack of predictability of an outbreak (Radwan et al., 2024). Proper knowledge of the climate change-induced changes in the biology and population dynamics of insect pests is thus necessary in the development of resilient and sustainable pest control interventions. Climate changes not only modify the abundance of the pests but also interfere with pest-natural enemy relationships, crop phenology, and the effectiveness of management (Radwan et al., 2024; Carley et al., 2025). The review consolidates the existing literature on climate-induced changes on the dynamics of insect pests in rice-wheat systems in the western part of India, in addition to incorporating reports all over the world to detect potential future challenges and climate-related management opportunities in the changing environment (Abbas et al., 2025; Burc et al., 2025).

## 2. Climate Change Scenario in Western India

Over the last few decades, Western India has been witnessing a gradual increase in mean annual

temperature ranges and heat waves are increasingly being witnessed, strange monsoon trends and extended dry seasons. This is essentially the trend that people discuss in relation to global warming and climatic changes all around the globe. In Indian agro-ecosystems, rising temperatures and fluctuating rainfall regimes have been shown to significantly affect cropping systems and pest population dynamics (Radwan *et al.*, 2024). Similar assessments at the global scale indicate that continued warming and precipitation variability will intensify stress on agricultural landscapes and pest management systems (Abbas *et al.*, 2025; Carley *et al.*, 2025).

Future climate projections for Western India suggest further temperature increases, greater inter-annual climatic variability, and elevated atmospheric CO<sub>2</sub> concentrations. These interacting drivers are expected to accelerate crop phenology, shorten growth duration, and modify crop developmental stages. Elevated CO<sub>2</sub> levels can alter plant physiological processes, including photosynthesis and carbon–nitrogen balance, thereby influencing herbivore feeding behavior and performance (Abbas *et al.*, 2025). Experimental and field-based studies further indicate that warming enhances insect metabolic rates, development speed, and reproductive potential, potentially amplifying pest population growth under favorable resource conditions (Burc *et al.*, 2025). Evidence from Indian agro-climatic conditions also confirms that temperature and moisture stress interact to influence pest buildup and seasonal occurrence (Radwan *et al.*, 2024).

Climate-induced environmental shifts also disrupt ecological synchrony among crops, insect pests, and their natural enemies. Changes in temperature and humidity affect insect survival, voltinism, dispersal capacity, and geographical range expansion (Carley *et al.*, 2025; Idigo *et al.*, 2025). Moreover, adaptive agronomic responses such as altered sowing dates and modified crop duration—implemented to cope with climatic stress—may unintentionally influence



pest life cycles and outbreak patterns. Radwan et al. (2024) reported that such agronomic and climatic interactions can disturb pest–natural enemy synchronization, in this effect, enhances the likelihood of the secondary pest attacks and uncertainties in the infestations. In my reading, global researchers have concluded that not only is global warming accelerating the development of pests, but it also appears to be allowing them to adjust to changing ecological conditions more easily, which, in its turn, increases long-term risks of agriculture (Burc et al., 2025; Abbas et al., 2025). Overall, the information indicates that climate change in Western India is not only a matter of a gradual increase in temperature but also a complex process of interdependence between temperature, change in the level of precipitation, and the concentration of CO<sub>2</sub> in the air. These are changing the nature of the interaction between crops, pests and the environment and are making the outbreaks of pests more unpredictable.

### 3. Effect of Climate Change on Insect Pest Biology

#### 3.1 Temperature Effects

Temperature is a significant abiotic condition that, in fact, conditions insect metabolism, development, growth, and reproduction. Increase in the temperature accelerates the development of insects, reduces their generation period, and increases the number of generation cycles in a year- this essentially increases the intensity of the pest pressure on the crops. Radwan *et al.* (2024) demonstrated that increased temperature contributes to swelling population in various farm pests and this trend has been emerging in other Agro-ecosystems across the world (Abbas et al., 2025). Warmer winters also contribute to the preservation of overwintering stages and this results in early infestations beginning earlier and longer pest activity. Conversely, when temperatures are too high to allow accommodation by the insects, it may damage their survival and

fitness, and therefore the thermal stress response is certainly species-specific (Abbas et al., 2025).

#### 3.2 Rainfall and Humidity Effects

The dynamics of insect pests are strongly influenced by rainfall and relative humidity along with temperature. The humidity is basically beneficial to aphids and planthoppers as they are not only hatching and surviving more, but are also thriving. Radwan et al. (2024) also argue that a high level of humidity accumulates groups of sap-sucking pests in cereals and other studies have also indicated that there is a positive correlation between humidity and pest survival (Abbas et al., 2025).

Conversely dry spells may increase to an infestation of pests that enjoy moisture stress.

Unpredictable precipitation may cause imbalance in predator-prey relationships and inefficiency of natural enemies, which causes increased population of pests (Abbas et al., 2025).

#### 3.3 Elevated CO<sub>2</sub> Effects

High concentrations of CO<sub>2</sub> in the atmosphere affect physiological processes of plants by causing plants to have a high amount of carbon and less nitrogen concentration in their tissues which lowers the nutritional value of the host plants. As a reaction, insect herbivores tend to compensate by feeding more intensively to satisfy their nutritional needs leading to crop destruction. Abbas et al. (2025) also showed that increased CO<sub>2</sub> level improves the rate of herbivore consumption and changes the growth and development of insects, and the same is also proved in the Indian cropping systems (Radwan et al., 2024). Also, high CO<sub>2</sub> level can affect Tri trophic interactions through the modulation of the plant defences and natural enemy functioning, resulting in the regulation of pests in changing climatic conditions.



**Table 1. Effect of Climate Change Factors on Insect Pest Biology**

Climate factor	Effect on insect pests	Consequence on crops
Rising temperature	Faster development, increased generations	Early and severe infestations
Erratic rainfall	Favors sap-feeding pests	Frequent outbreaks
Increased humidity	Higher survival of soft-bodied insects	Increased damage
Elevated CO <sub>2</sub>	Increased feeding rate	Greater yield loss

**4. Climate change effects on insect pest dynamics in the rice–wheat cropping system in Western India.**

**4.1 Changing Dynamics of Major Rice Insect Pests**

Climate change significantly increases the population of the stem borers, leaf folders, the planthoppers and the gall midges. An increase in temperature causes them to grow faster, reduces their life cycles and allows them to generate more generations which translates into more concerns of infestation. According to Radwan et al. (2024), warming accelerates the increase in the population of pests in rice fields and Abbas et al. (2025) observe the same worldwide. The other element is that of high humidity and warm climate particularly when the rice farms are highly intensive. This contributes to the planning of the outbreaks of plant hoppers to be more common and more serious as they remain alive and are able to reproduce better. The re-appearance of the pests and increased rice losses is contributed by changes in the timing of crops, varying planting dates and numerous varieties of high yields. According to Radwan et al. (2024), climate changes in the nature

of our farming can disrupt the balance between pests and their natural predators, exposing rice to attacks, which also Abbas et al. (2025) confirm all over the world.

**Table 2. Major Insect Pests of Rice and Wheat and Climate-Induced Changes**

Crop	Major pests	Climate-driven changes
Rice	Stem borers, leaf folders	increased generations
Rice	Planthoppers	Frequent outbreaks
Wheat	Aphids	Higher survival in warm winters
Wheat	Termites	Increased activity under dry conditions

**4.2. Changing Dynamics of Major Wheat Insect Pests**

Gradual warming and reduced winter are increasingly providing favourable environments in agro-ecosystems based on wheat, such as a bunch of economically significant insect pests, such as aphids (*Sitobion avenae*, *Rhopalosiphum padi*), termites (*Odontotermes spp.*), and armyworms (*Mythimna spp.*). I have witnessed the acceleration of insect metabolism, a decrease in generation time, and an increase in reproductive rates due to high temperature, and this implies that the population can grow at even faster rates. In cereal cropping systems, warmer conditions have been associated with highly aphid infestation windows and colony growth rates is higher, thereby intensifying direct feeding damage and increasing the likelihood of virus transmission (Radwan et al., 2024; Abbas et al., 2025). Experimental and modelling studies also indicate that a thermal-adaptation to climate warming might increase the proportionality of aphid populations and feeding rates, worsening the loss of yields in wheat (Burc et al., 2025).



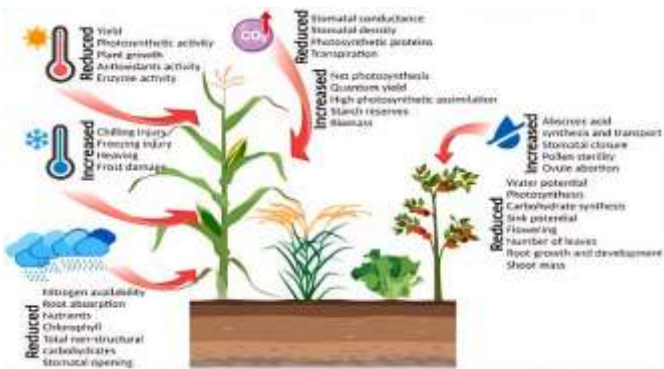


Figure 1. Subedi et al. 2023

The number indicates that the decrease in extreme cases of cold also allows **aphids** to survive during winter and colonise fields earlier and remain longer there (Carley et al., 2025). Additionally, increasing the temperature could impact the competence of the vectors and development of the pathogens within the insects, increasing the chances of cereal crop viral epidemics (Idigo et al., 2025).

In the case of **termites**, particularly in rainfed and semi-arid areas of wheat production, they are highly sensitive to soil moisture variation. Long droughts and moisture stress literally form sweet spots where termites forage and expand their colonies that feed more on roots, kill seedlings, and cause patchy crop establishment. In the agro-climatic conditions of India in wheat fields, one of the primary causes of termite infestation is climate-induced drying of soil (Radwan et al., 2024). The climate change is also changing the ranges and distribution patterns of **armyworms** and other lepidopterans defoliators. The variation in temperature can also change when they move onwards, the rate at which the larvae grow, and their success in developing populations (Abbas et al.; 2025). Trends of hot spots might drive them to colder regions and increase the risks of infestations of a rare but severe nature (Carley et al., 2025). Shifts in wheat phenology due to climate may also confuse the relationship among the pests and the crop and result in less predictable and more unpredictable infestations.

All this demonstrates that climate variability; increasing temperatures, changing rainfall patterns

and reduced winters are causing pests to be confused in terms of their survival, reproduction, dispersal and interaction with their hosts in wheat ecosystems. These changes interrupt the ecological system and increase yield instability, facing significant challenges for sustainable wheat production under future climate scenarios (Radwan et al., 2024; Abbas et al., 2025; Burc et al., 2025).

### 5. Regional Variations in Pest Incidence

The incidence rates of pests also vary depending on the areas because of variations in temperature, rainfall distribution, cropping and the landscape structure. Warmer regions tend to have increased pest pressure and longer durations of pest activity and cooler regions Subedi et al. 2023 experiencing the occurrence an few species of pests. According to Radwan et al. (2024), climate-driven changes in thermal regimes have facilitated pest range expansion and altered regional pest assemble in agricultural systems.

Spatial invariance of climatic conditions also has an impact on the performance of natural enemies and pest checks. Pests distribution and their increase are also affected by climatic changes, which presents new challenges in the process of pest surveillance, prediction, and a region-based management approach. The same patterns of redistribution of pests during climate change have been reported at the global level (Abbas et al., 2025).

### 6. Implications for Pest Management

Climate change literally puts a spanner in the works of the common pest management techniques that we study in school. As the pests have an earlier appearance, longer lifespan and even an extra generation or so every year, the time of pesticide spraying is everywhere at the same time. It implies that the chemicals that we use will not reach the pests as readily as they are the most susceptible, resulting in reduced control efficacy and increased crop losses (Radwan et al., 2024; Carley et al., 2025). Increased-



temperature conditions put the farmers in the situation that they are forced to apply a greater Number of insecticides and at a very high rate. To us, as students studying these systems, it is obvious that this additional usage does not only increase the costs, but also accelerates the adaptation of resistance in pest populations (Radwan et al., 2024). In addition, an increase in temperature may alter insect physiology and detoxification routes, and may make the resistance even more resistant and alter the toxicity of the pesticides (Burc et al., 2025). This ecological blowback is bad news to biological control. Swings in temperature and humidity can strike pests and their natural enemies in completely dissimilar manners, breaking the synchrony of life cycles, and compromising those interactions in the food-webs with which we have become trained. Advantageous arthropods, predators, and parasitoids may be more adapted to heat than the pests, which steals the natural regulation ability (Carley et al., 2025). To make matters worse, warming may cause changes in the pathogen development and the ability of vectors in insects, altering disease dynamics and complicating the concept of integrated pest management (IPM) (Idigo et al., 2025). According to global studies, all these climate-related changes imply that we have to adjust our pest-management methods to those that can even survive in the changing climate (Abbas et al., 2025). This involves improved forecasting tools with climate information, breeding more resistant types of crops, supporting and preserving natural predators, establishing more biodiverse habitats, and adopting more precise ag technology. In a nutshell, it is important to tighten IPM during the climate change time in order to ensure that we maintain crop productivity and reduce environmental and economic risk.

**Table 3. Climate Change Impacts on Pest Management**

Aspect	Impact
Chemical control	Reduced efficacy,

	resistance risk
<b>Biological control</b>	Pest–enemy asynchrony
<b>IPM</b>	Need for climate-resilient strategies



Figure 2. Climate- Smart pest management framework integrating forecasting, biological control, and IPM (Integrating pest managements) (Bouri et al. 2023).

**7. Climate-Smart Pest Management Strategies**

Climate-smart pest management strategies are emphasizing adaptive and sustainable approaches to address climate-driven changes in pest dynamics. It is a matter of keeping up to climatic-driven changes in pest dynamics without going unsustainable. The most important strategies that I have acquired are climate-based pest forecasting, conservation biological control, adoption of pest resistant varieties of crops, adjustment of sowing dates and a combination of cultural and biological and specific chemical control. Radwan et al. (2024) highlighted that incorporating climate information into pest management decisions improves the timing and effectiveness of interventions of Pest, thereby reducing related to pests risks under different-different climatic conditions. Integrating climate data into integrated pest management (IPM) frameworks enhances system resilience by enabling proactive rather than reactive pest control. The concept of climate-informed IPM minimizing the use of pesticides and maintaining the ecological balance despite the change in the climate is supported by global studies (Abbas et al., 2025).



## 8. Conclusion

I have been reading of how climate change is completely redefining the dynamics of the insect pests in West Indian rice-wheat systems. In essence, warming, bizarre monsoon trends, extended dry seasons, and elevated CO<sub>2</sub> all are meddling with the pest survival, growth, reproduction, movement, and interaction with crops. These alterations in the environment are accelerating the increase in the population of pests, increasing voltinism, extending their geographic dispersion, and increasing outbreaks in both rice and wheat ecosystems (Radwan *et al.*, 2024; Abbas *et al.*, 2025; Carley *et al.*, 2025). The ecological disturbance in the timing of crop growing and the adjustments by farmers due to the climatic conditions also disrupts the timing on pests and their host plant, disrupting the entire ecosystem. This undermines natural control, thus necessitating the increased use of chemicals, which further increases the chances of resistance and environmental harm (Radwan *et al.*, 2024; Burc *et al.*, 2025). Furthermore, changes in the biology of insects and the capacity to transmit diseases due to climate changes may increase the severity of the transmission of plant diseases, further exposing production to risk (Idigo *et al.*, 2025).

All these climate-based changes pose a threat to the yields, farm profits, and local food security. This is why it is important to switch to climate-resilient and adaptive pest management. Integrating real-time climate information, pest forecasting models, resistant crop varieties, ecological engineering, and strengthened Integrated Pest Management (IPM) approaches will be essential to Reduce future pest-related risks (Carley *et al.*, 2025).

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## Genome Wide Association Study (GWAS) based identification of novel alleles responsible for disease resistant in plants

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Genome Wide Association Study (GWAS) have enabled for the identification of genetic variants linked with disease resistant in plants. It generally performs scanning of entire genome for single nucleotide polymorphism (SNPs) that are associated with phenotypic traits like disease resistance. Due to its high-resolution mapping capacity it has enables the discovery of major and minor plant disease resistant loci. By integrating with modern omics tools, it can faster the development of high yielding disease resistant crop varieties..

### Introduction

In terms of global productivity and food security, diseases caused by plant pathogens creates a major constraint to this sector. Globally, there is significant yield losses and reduce in crop quality can be observe due to infestation caused by plant pathogens like fungi, bacteria, viruses and nematodes (Dutta *et al.*, 2022). The problem associated with these biotic stresses can be overcome by implementation of diseases resistant crop varieties, as it can reduce pathogens infection and multiplication in the plant host (Dutta *et al.*, 2022). Since decades, development of disease resistant crop varieties has been played a central role in majority of the plant breeding programs, which are mainly obtained based on traditional breeding programmes. Traditional breeding approaches are in many of the cases found successful but they are although time consuming and they are limited to identify germplasm which are resistance in nature (Lamichhane and Thapa, 2022). Classical genetic mapping methods like quantitative trait locus (QTL) based on biparental approaches has played a significant role in identification of diseases resistant genes that are present in genomic regions which contribute for quantitative and qualitative resistance in a particular trait (Kulwal and Singh, 2022). But due to their dependency only on the

crosses between the biparental lines, it faces challenges to study the wide allelic diversity. Therefore, to overcome this limitations, recent genome wide analytical methods has enabled us to identify diversity of novel alleles that are mainly associate with plant disease resistance mechanism. Recent studies on advances in molecular and biotechnological approaches has provided an insight understanding about disease resistance at genetic level and also modern technologies like Genome wide Association Studies (GWAS) has transformed our ability to understand disease resistance in plants and also help us to identify novel diseases resistant alleles to implement it in the crop improvement sector (Bocianowski, 2024; Dubey and Mohanan, 2024). GWAS approach mainly exploits diverse breeding populations based on historical events related to diverse natural or breeding populations to corelated with the variation at the phenotypic level by understanding the genetic markers that are mainly distributed across the entire genome. GWAS approach by analysing the millions of single nucleotide polymorphisms (SNPs), it provides high resolution mapping of loci that are linked with disease resistance characteristics (Mkize *et al.*, 2021). Thus, it allows us to identify the disease resistance alleles without developing specialised



mapping population. Till date this approach has been successfully implemented in many crops like rice, wheat, maize, soya bean, tobacco etc. (Khalid *et al.*, 2025) where novel alleles associated with disease resistance has been identified through this GWAS approach.

**Mechanism of GWAS based disease resistant gene identification**

In recent years, GWAS based genetic analysis are mainly performed to identify the novel candidate gene responsible for disease resistance. The main principle behind this approach is to find out the genetic variation loci like single nucleotide polymorphism (SNPs) which are associated with target traits with different genotypic characteristics that are then compared with the different phenotypic characteristics of the individuals or populations. For this, large and diverse population of plant lines including land races and wild cultivars are required to study the wide range of alleles that has been accumulated through historical recombination so that their precise mapping can be done to identify the resistant traits. Initially it collects large scale genotypic and phenotypic data and their association between them are analysed with the help of statistical methods. This can be achieved by collecting the genotypic and phenotypic data from a representative population with the help of gene clip technology or high throughput sequencing technology. After the collection of the data, the association between the genotype and phenotype are analysed with the help of statistical methods like Chi-square test, linear regression, logistic regression etc. (Jiang, 2024). Modern mixed linear and multi locus models accounts for both phenotypic and genotypic characteristics are used to detect true resistance loci while it also accused for minimising false positive reports. Principle component analysis (PCA), QQ-Plots and heatmaps serves as tools that performs quality control and data visualization. These tools are required to ensure robust identification of alleles that are disease resistant in plants and also these tools help

in mitigating the false positive results and linkage patterns. Several software packages like GenStat, TASSEL, PLINK etc. used of identification of disease resistant allele in plants where it handles population structure correlation, association testing and data visualization. The data are mainly visualised by using Manthattan plots, where the genomic regions showing significant characteristics are appears as peak.

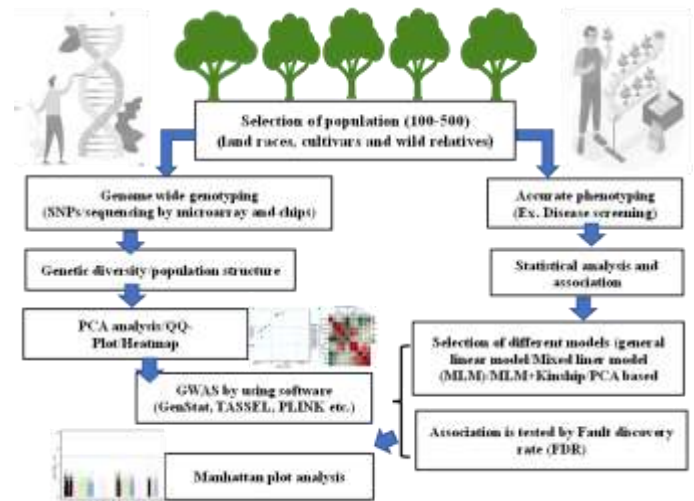


Fig 1: Workflow of Genome Wide Association Study (GWAS)

**Examples of GWAS based resistant gene identification in plant**

Based on GWAS several studies have been conducted across the world to identify the disease resistance gene in plants by QTL mapping or SNPs that are linked with disease resistance against plant pathogens. Kavuluko *et al.* (2021) have reported the role of GWAS based identification of mechanisms involved in parasitic plant (*Striga*) resistance in Sorghum. They have elucidated the genetic loci underlying the resistance using GWAS studies. GWAS based studies was also found to be useful for identification of genes or the genetic factors for head smut resistance in maize crop. Based on this, Wang *et al.* (2012) have reported that, GWAS of head smut of maize and by suing the Illumina Maize SNP50 array, total 18 novel candidate gene out of 45,868 SNPs in a panel of 144 inbreed lines were found associate with the head smut resistance in maize crop.



GWAS has played a significant role in the identification of genetic loci that are associated with the rough dwarf disease resistance in maize crop. By integrating GWAS and linkage mapping methods, Zhao *et al.* (2022) identified total 22 SNPs that are distributed on the chromosome 1, 3, 4, 6, 7 and 8 were associated with the maize rough dwarf disease resistance mechanisms. They also reported that, the candidate genes that were identified by the help of GWAS include LRR receptor like serine and other genes which are responsible for disease resistance in maize. For identification of disease resistance gene against blast of rice was also evaluated by GWAS to uncover significant regions of genes that encodes for proteins that resist blast disease in Northeast India (Barua *et al.*, 2024). By integrative application of GWAS with transcriptomic study, total 41 significant SNPs associated with resistance to root rot disease in alfalfa caused by *Fusarium oxysporum* were identified which were found across eight chromosomes responsible for disease resistance (He *et al.*, 2025). GWAS also has revealed novel resistance locus on chromosome 4D for Karnal bunt of wheat from diverse pre-breeding germplasm. Through GWAS 6,382 high quality DArTseq SNPs revealed 15 significant SNPs that were associated with resistance mechanism against this disease in wheat crop (Singh *et al.*, 2020). Multi locus GWAS also has identified 24 QTLs for resistance against several bacterial disease in common bean. Out of which nine QTLs controlled bacterial brown spot caused by *Pseudomonas syringae* pv. *syringae*, eight QTLs for common bacterial blight of bean caused by *Xanthomonas* spp. and remaining seven QTLs for halo blight of bean caused by *Pseudomonas syringae* pv. *phaseolicola* (Soler-Garzón *et al.*, 2024). To identify the QTLs (Quantitative trait loci) for leaf spot disease resistance in the cultivated peanuts, two QTLs on the ChrB09 were identified by GWAS and were found to be associated with both early and late leaf spot disease resistance in cultivated peanut (Zhang *et al.*, 2020). Thus, GWAS have played an instrumental role in identifying resistance genes

against several plant pathogens by analysing the genetic variation in diverse crop by uncovering the QTSs and SNPs that are associated with disease resistance.

**Table 1: Some of the key research works carried out to identify disease resistant alleles/QTLs in crop using GWAS**

Year	Author	Key findings
2012	Wang <i>et al.</i>	Identified 18 novel candidate genes associated with head smut resistance from 45,868 SNPs in 144 maize inbred lines by GWAS approach
2020	Singh <i>et al.</i>	GWAS of pre-breeding germplasm revealed novel resistant locus on chromosome 4D for Karnal bunt resistance in wheat. Total 15 significant SNPs from 6,382 high quality DArTseq markers were identified.
2020	Zhang <i>et al.</i>	Identified two major QTLs on chromosome B09 that are associated with disease resistance for both early and late leaf spot in cultivated peanuts.
2021	Kavuluko <i>et al.</i>	Identified genetic loci and resistance mechanism involved in parasitic plant ( <i>Striga</i> ) in sorghum. Elucidated key genomic regions underlying this resistance mechanism.
2022	Zhao <i>et al.</i>	Studied the role of integrative use of GWAS and linkage mapping to identify the SNPs across



		different chromosomes that are associated with rough dwarf disease resistance in maize crop.
2024	Barua <i>et al.</i>	GWAS has revealed significant genomic regions encodes for defence related proteins for blast resistance in rice genotypes from Northeast India.
2024	Soler-Garzón <i>et al.</i>	Reported that multi-locus based GWAS has identified 24 QTLs for bacterial disease resistance in common bean plant. They have identified 9 QTLs for bacterial brown spot, 8 QTLs for common bacterial blight and 7 QTLs for halo blight of bean.
2025	He <i>et al.</i>	GWAS coupled with transcriptomic analysis has revealed 41 significant SNPs across eight chromosomes that are mainly associated with root rot resistance in alfalfa plant.

**Application of GWAS in terms of identification of disease resistant genes in plants**

By analysing large scale genotype and phenotype data disease resistant traits in an individual or in a population, GWAS helps to identify candidate gene responsible for resistance mechanism. These genes and sometimes the molecular markers are used for the selection or development of disease resistant cultivars. Researchers can identify disease resistant molecular markers by the help of GWAS to precisely identify the crop varieties that are having disease resistant genotypes and also this helps in speeding up the breeding processes. Thus, by implementing

GWAS in plant breeding studies for identification of disease resistance cultivars helps in promoting sustainable development of agricultural production (Jiang, 2024).

**Conclusion:** In conclusion, the GWAS have played a significant role in identification of novel candidate gene responsible for disease resistant in plants. In future, application of GWAS with other broad-spectrum tools like next generation sequencing can help to contribute in identification of novel disease resistant genes in plants and thus it will promote sustainable agriculture and food security.

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# Roots of Roots: The Hidden World of Mycorrhizae

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Mycorrhizae are symbiotic associations between plant roots and soil fungi that play a crucial role in soil fertility and sustainable agriculture. Through an extensive hyphal network, they enhance uptake of immobile nutrients and water, while improving plant tolerance to environmental stresses. In addition to promoting plant nutrition, mycorrhizae improve soil aggregation and stimulate biological activity, thereby supporting long – term soil health. Therefore, the integration of mycorrhizal management into agricultural systems is essential for developing resilient, low – input and sustainable cropping systems.

## Introduction

Beneath the visible growth and productivity of crops lies a complex and largely unseen biological system that plays a fundamental role in plant and soil health. While agricultural productivity is often evaluated in terms of fertilizer inputs and yield outputs, the true foundation of soil fertility is governed by dynamic biological interactions occurring within the rhizosphere. Among these, mycorrhizae i.e., the symbiotic association between soil fungi and plant roots, represent one of the most significant and beneficial relationship in terrestrial ecosystems. Often referred to as the “roots of roots”, the mycorrhizal fungi colonize plant roots and extend extensive networks of fine hyphae into surrounding soil zones beyond the reach of root hairs. This expanded surface area of roots helps in improving the uptake of relatively immobile nutrients, particularly phosphorus, along with essential micronutrients and water.

In exchange for photosynthetically derived carbohydrates from the host plant, mycorrhizal fungi improve nutrient use efficiency, strengthen drought tolerance and contribute to overall plant vigour. Beyond their role in nutrient acquisition, these fungi enhance soil structure through the formation of stable aggregates, thereby supporting long – term soil fertility. Such interactions underscore the concept of soil as a living ecosystem rather than a passive

growth medium. However, intensive agricultural practices viz., excessive tillage and injudicious use of chemical inputs, disrupt these fungal networks, reducing their ecological functions. Thus, the recognition and conservation of mycorrhizae within agricultural management frameworks are essential for achieving resilient cropping systems and long – term soil health.

## Types of mycorrhizae

Mycorrhizal associations are diverse and widespread across terrestrial ecosystems. The two most common types are arbuscular mycorrhizae (AM) and ectomycorrhiza (ECM). Most abundant among these is arbuscular mycorrhiza which is associated with 80 per cent of land plants including the majority of agricultural crops (Willis *et al.*, 2013). Ectomycorrhiza on the other hand, primarily associate with woody perennials such as oaks, pines and eucalyptus. Unlike AM fungi, they form a dense fungal mantle around the root surface and develop an intercellular network between cortical cells known as Hartig net, which facilitates nutrient exchange. Other types include ericoid mycorrhizae and orchid mycorrhizae. Ericoid mycorrhizae typically occur in plants growing in acidic and nutrient poor environment. These fungi form loose intracellular coils within root cells and help mobilizing nutrients from complex organic matter. Orchid mycorrhizae, on other hand, play a critical role during the early



developmental stages of orchids. Since orchid seeds are extremely small and lack sufficient nutrient reserves, the fungal help supplying essential nutrients required for germination and early growth. Despite differences in structural organization and functional mechanisms, all forms of mycorrhizae play a vital role in nutrient uptake, stress mitigation and overall ecosystem functioning.

**Mechanism**

Mycorrhizal associations operate through distinct but functionally similar mechanisms depending on the type. In arbuscular mycorrhizae (AM or VAM), the interaction begins with pre – symbiotic signalling in the rhizosphere, where roots release signalling molecules known as strigolactones that stimulate fungal spore germination and hyphal growth toward the root. Upon contact, the fungus penetrates the root epidermis and colonizes cortical cells, forming highly branched structures called arbuscules that serve as primary sites of nutrient exchange. In some cases, vesicles are also formed for storage. The fungus simultaneously develops an extensive hyphal network in soil with roots, expanding absorptive surface area and enhancing the uptake of relatively immobile nutrients. At the arbuscular interface, a bidirectional nutrient exchange occurs wherein the nutrients are transferred to the plant in return for photosynthetically derived carbon compounds (Fig. 1).

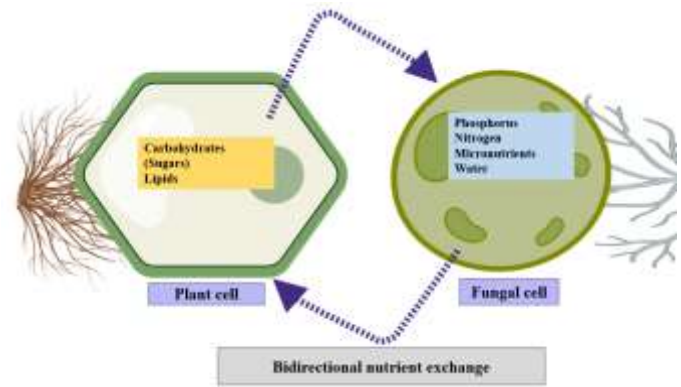


Fig. 1. Mechanism of arbuscular mycorrhizal (AM) symbiosis

In ectomycorrhiza, the fungus does not penetrate root cells instead forms dense mantle around roots and develops an intercellular network (Hartig net), which facilitates nutrient exchange (Fig. 2). From this structure, nutrients absorbed by the external hyphal network get transferred to the host plant, while carbon compounds from plant to fungus. ECM produce wide range of extracellular enzymes that enable breakdown of complex organic matter, allowing efficient mobilization of organic forms of nitrogen and phosphorus commonly found in forest soils, ultimately stabilizing woodland ecosystems.

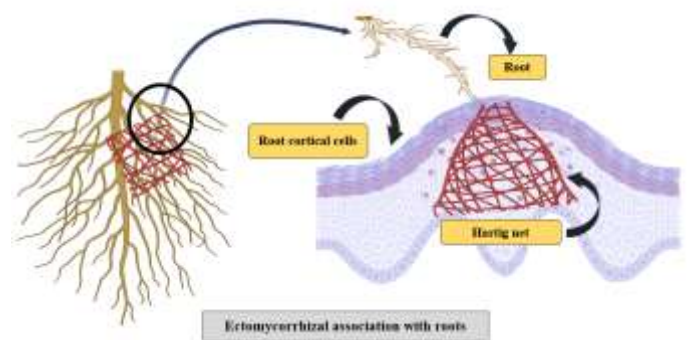
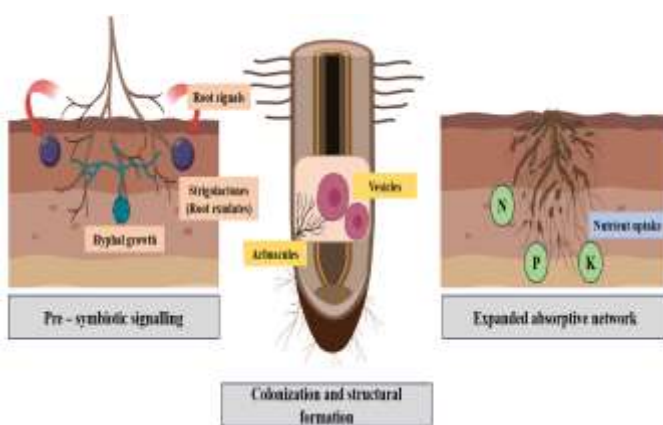


Fig. 2. Mechanism of ectomycorrhizal (ECM) symbiosis

**Functional role of mycorrhizae in agriculture**

In current agriculture scenario, where soil degradation and environmental stresses are increasing, mycorrhizal associations provide biologically driven mechanism to improve crop performance while reducing dependence on chemical



inputs. All in all, the functional significance of mycorrhizae extends beyond plant nutrition to overall agroecosystem stability and resilience. The major contributions of mycorrhizae in agricultural systems may be discussed under the following aspects:

### 1. Enhancement of nutrient uptake and nutrient use efficiency

As discussed earlier, the extensive hyphal network of mycorrhizae expands the effective root surface area, thereby facilitating enhanced nutrient uptake, particularly of immobile nutrients in soil. Several studies have demonstrated the beneficial effect of mycorrhizal fungi on crop performance. The inoculation of wheat with AMF alone or in combination with 25% of recommended dose of fertilizers, significantly improved biomass, root colonization and yield compared to full fertilizer application (Mandou *et al.*, 2023). In another study using <sup>15</sup>N isotope labelling under both field and pot conditions, AMF inoculation significantly enhanced plant biomass, nitrogen uptake and nitrogen use efficiency in wheat (Xue *et al.*, 2024).

### 2. Mitigation of abiotic and biotic stress

Mycorrhizal associations play a major role in improving plant tolerance to abiotic stresses such as salinity and drought. Salinity stress is one of the major abiotic constraints limiting agricultural productivity, particularly in arid and semi – arid regions. Excess accumulation of soluble salts in the soil increases osmotic stress, reduces water availability to plants and leads to ionic toxicity primarily due to Na<sup>+</sup> and Cl<sup>-</sup> ions. High salinity disrupts nutrient balance, inhibits root growth, impairs photosynthesis and enhances production of reactive oxygen species, ultimately reducing crop quality and yield. AM fungi improve plant water relations and contribute to the maintenance of ionic balance. Moreover, they stimulate the activity of antioxidant enzymes, thereby reducing oxidative damage induced by salt stress. A greenhouse study in

tomato showed that inoculation with *Claroideoglossum etunicatum* combined with exogenous trehalose significantly enhanced salt tolerance (Chen *et al.*, 2024). Drought stress severely limits crop growth by reducing water availability, cell turgor and photosynthetic activity. Mycorrhizal fungi enhance drought tolerance by improving soil water exploration through their extensive hyphal network and maintaining better plant water status. They also promote osmotic adjustment through accumulation of solutes like proline and sugars. Additionally, increased antioxidant activity in mycorrhizal plants helps reduce oxidative damage under water-deficit conditions. A meta – analysis across crops such as wheat, maize, rice and soybean showed that AMF inoculation improves drought tolerance by enhancing antioxidant enzymes (SOD, POD, CAT and APX), although the magnitude of response varied with plant and AMF species (Murugesan & Paramasivan, 2022).

Further, mycorrhizae mitigate biotic stresses by strengthening plant defense and improving overall vigour. They suppress soil – borne pathogens such as *Pythium*, *Rhizoctonia*, *Fusarium*, reduce root – knot nematodes (*Meloidogyne* spp.) and limit parasitic weeds like *Striga* and *Orobanche* through induced systemic resistance. Their protective effects arise from enhanced defense activation and beneficial rhizosphere interactions. A study in alfalfa showed that AMF (*Rhizophagus intraradices*) improved plant resistance against aphids and foliar pathogens by enhancing defense enzymes and maintaining beneficial phyllospheric microbes (Wang *et al.*, 2025).

### 3. Contribution to soil health and sustainability

Beyond their benefits to plant nutrition, mycorrhizal fungi significantly strengthen soil physical, chemical and biological properties, thereby enhancing overall soil sustainability. The mycorrhizae promote aggregation of soil particles through their hyphal



networks and secretion of binding compounds such as glomalin. Improved aggregation enhances water retention, root penetration and resistance to compaction. Mycorrhizal networks also stimulate beneficial microbial communities and facilitate efficient nutrient cycling, ultimately maintaining soil biological activity. Various studies highlighted the functional role of AMF hyphae and glomalin related soil proteins (GRSP) in soil aggregate formation and stabilization (Parihar *et al.*, 2020). Wright and Upadhyaya (1996) reported a strong positive correlation between GRSP concentration, hyphal length and aggregate stability, indicating greater carbon storage with increased aggregation.

### Conclusions

Mycorrhizal associations represent a fundamental biological component of sustainable agriculture, linking plant productivity with soil health and ecosystem stability. Through enhanced nutrient acquisition, improved stress tolerance, biocontrol potential and soil structural development, mycorrhizae contribute significantly to resilient and low input farming systems. In view of their multifaceted benefits, mycorrhizae emerge as a cornerstone of sustainable agriculture, supporting productive, climate – resilient and ecologically balanced crop production systems.

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# Ornamental Fisheries: India's Shining Gem Beneath the Water

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When I think of fish farming in India, our minds usually jump to carp, catfish, or prawns species that fill our plates. But beneath the calm waters of our oceans, lakes, rivers and ponds lies a dazzling world of color the ornamental fish industry. These vibrant aquatic beauties from guppies and goldfish to exotic marine species are more than a hobbyist's delight. Ornamental fishkeeping is a hobby where attractive, colorful fish, also known as "live jewels," are kept as pets in confined spaces such as aquariums or garden pools, primarily for the enjoyment of their beauty and aesthetics. They represent a promising, eco-friendly, and profitable sector for rural and coastal communities across India.

## A Journey from Hobby to Industry

Ornamental fish keeping is the second most popular hobby in the world, next only to photography, with nearly 100 million enthusiasts across the globe. In India, its roots can be traced back to the early 1900s, when keeping aquariums was simply a pastime for a few passionate hobbyists. Over time, this quiet hobby has evolved into a vibrant activity with promising economic and livelihood potential. Despite India's rich aquatic biodiversity and favorable climate, the country's share in the global ornamental fish trade remains modest, contributing only 0.53 percent of global exports and 0.42 percent of imports (Department of Fisheries, 2023). Recognizing the scope for growth, states such as West Bengal, Tamil Nadu, Maharashtra, Kerala, Odisha, Gujarat, Karnataka, Assam, and Manipur have been identified as key regions for the development of ornamental fisheries. A major milestone was reached in 1987 with the establishment of the Central Institute of Freshwater Aquaculture (CIFA), which initiated dedicated research, training, and breeding programs in ornamental fish culture. Since then, ornamental fish farming in India has developed into a thriving small-scale enterprise, providing income and

employment opportunities to thousands of people, particularly women and youth, across the country.

## Economic Importance: Tiny Fish, Big Profit

The ornamental fish industry plays an important role in generating income, employment, and promoting biodiversity conservation. It supports a variety of allied sectors, including aquarium manufacturing, fish feed production, decorative plant supply, and tourism, thereby contributing to the broader fisheries economy. India's fisheries sector accounts for approximately 6.4% of agricultural GDP, with ornamental fish farming adding to this growth through high-value products and export potential (Immanuel et al., 2013). Domestically, the ornamental fish trade is valued at around USD 3–4 million, while exports have steadily increased from USD 0.67 million in 2015–16 to over USD 4.5 million in 2021–22, reflecting strong growth in both quantity and value. The Indian ornamental fish market is projected to grow from USD 160.12 million in FY2024 to USD 346.24 million by FY2032, at a CAGR of 10.12%, driven by increasing urbanization, rising disposable incomes, and changing lifestyle preferences.



Globally, the ornamental fish trade generates over USD 6 billion annually, yet India contributes less than 1%, despite trading 187 species, most of which are wild-caught (Immanuel et al., 2013). The northeastern region of India, particularly Tripura, has immense but underutilized potential for ornamental fish production. Tripura contributes significantly to the region's exports, with opportunities for cultivating both native and exotic species; however, challenges such as inadequate infrastructure, high initial investment, limited government support, and scarcity of quality broodstock remain (Das et al., 2013). Across India, nearly 5,000 production units operate, with West Bengal leading (55%), followed by Tamil Nadu, Kerala, and Maharashtra. According to ICAR-CIFA, the Indian ornamental fish industry is valued at around ₹3,000 crore, including breeding, rearing, trade of ornamental fishes, aquarium accessories, aquatic plants, and decorative items, contributing significantly to employment and entrepreneurship.

Beyond commercial production, backyard ornamental fish farming has also emerged as a tool for socio-economic empowerment, particularly for women. Interventions by ICAR-CIFRI under the Pradhan Mantri Matsya Sampada Yojana (PMMSY) have enabled rural women, including tribal and Scheduled Caste beneficiaries, to generate steady income within months, establish their own ornamental fish units, and improve livelihood security. Although challenges such as limited market access persist, these initiatives support sustainable livelihoods, enhance family income, reduce migration, and promote social and economic empowerment in rural communities (Bhattacharya et al., 2025).

### Challenges Beneath the Surface

Despite its promise, India's ornamental fisheries face multiple challenges: lack of infrastructure, unsustainable wild collection, disease outbreaks, and regulatory hurdles. To overcome these, better

coordination between government, research institutions, and entrepreneurs is essential. Initiatives under the Department of Fisheries, MPEDA, and PM Matsya Sampada Yojana (PMMSY) have already started strengthening this sector through capacity-building, credit support, and marketing promotion.

### Opportunities: A Golden Future Awaits

India is home to over 374 freshwater and 700 marine fish species, with many having ornamental value. From the Western Ghats to the Brahmaputra valley, these waters are teeming with colorful treasures waiting to be cultivated responsibly. Promising areas include breeding indigenous species, developing eco-tourism and aquarium parks, training rural youth, and adopting modern technologies like recirculatory aquaculture and genetic improvement. With investment in infrastructure and marketing, India could easily transform into a major exporter of ornamental fish, catering to both domestic and global hobbyists.

### Sustainability: Protecting Water Beauty for the Future

Sustainability must remain at the heart of ornamental fisheries. Overexploitation of wild stocks and destruction of coral reefs or freshwater habitats can have lasting ecological consequences. Promoting captive breeding, enforcing trade regulations, and creating conservation zones will help maintain biodiversity while ensuring economic returns.

The future of ornamental fisheries in India looks bright. Emerging trends like e-commerce sales of aquarium species, eco-certified breeding, and international partnerships will redefine the sector's landscape. States like Assam, Kerala, West Bengal, and Tamil Nadu are already demonstrating success stories. If the government, private investors, and researchers continue to work hand in hand, ornamental fish farming can become a sustainable blue revolution combining economic growth with ecological balance.



**Conclusion**

Ornamental fisheries are not just about beauty in aquariums they represent a blend of science, art, and livelihood. With its rich aquatic biodiversity and growing domestic market, India stands at the threshold of becoming a global leader in this colorful industry. Empowering local entrepreneurs, ensuring sustainable practices, and investing in innovation will help this hidden gem of aquaculture shine brighter both at home and abroad.

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# Sensor-Based Technology in Aquaculture

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Aquaculture is among the most rapidly expanding food production industries globally, significantly contributing to meeting the growing demand for healthy sustainable seafood. Intensive aquaculture methods frequently encounter issues related to water quality decline, disease outbreaks environmental contamination, and inefficient resource utilization. Technology based on sensors has developed into an efficient approach to tackle these challenges by allowing real-time ongoing observation of physical chemical biological, and behavioural factors in aquaculture systems. Sensor-driven systems when combined with automation and artificial intelligence, enhance feeding, aeration and water management while facilitating predictive analytics for disease and environmental stress. Even with challenges like elevated start-up expenses and technical skill, sensor-based aquaculture greatly enhances productivity animal well-being resource use and environmental sustainability. The implementation of sensor-driven technologies signifies an important leap forward for intelligent robust and sustainable aquaculture progress.

## Introduction

Aquaculture, the practice of cultivating aquatic species like fish, shrimp, and shellfish, is among the fastest-expanding food production sectors worldwide, focused on meeting the increasing demand for healthy and sustainable seafood. In an intensive aquaculture system, where the fish are cultured intensively through high usage of resources, concerns related to water consumption, ecological effects, and animal wellbeing associated with water quality in the system arise. Among the different elements impacting aquaculture productivity, water quality stands out as the most vital, since it directly influences growth, survival, immunity, and the overall performance of cultivated species. Even minor declines in water parameters like temperature, dissolved oxygen, pH, ammonia, and turbidity can result in stress, disease outbreaks, and significant mortality. In this setting, sensor-driven technologies have arisen as effective instruments for accurate and

ongoing assessment of water quality. Sensors facilitate early identification of adverse conditions and prompt management actions by supplying real-time information on contamination levels and physicochemical factors. The incorporation of sensors in aquaculture systems aids in effective water recycling, decreases waste output, lowers environmental contamination, and improves long-term sustainability. As a result, sensor-based water quality monitoring is essential for enhancing productivity, safeguarding animal welfare, and encouraging sustainable aquaculture methods.

## Sensors in Aquaculture

Sensors are devices that detect and measure physical, chemical, or biological parameters and convert them into readable signals. Dissolved oxygen, Temperature, pH, and total dissolved solids are important variables in aquaculture that are measured by using sensors. Maintaining the quality of water in an aquaculture system is related to the viability and



sustainability of aquaculture. The overseeing and controlling of fish culture within optimal safe standard limits are crucial, as even the slightest changes in the water might be fatal to the cultured fish. Thus, the need for sensors in the aquaculture system becomes important as they facilitate the quick reading of water quality and other alterations in the system, as inadequate monitoring always leads to a disaster. Sensors in aquaculture facilitate precision farming, improving fish health and growth, reducing mortality, and enabling automated, data-driven management via IoT, which reduces environmental impact and operating costs.

### Types of Sensors used in Aquaculture

#### Water Quality Sensors

Water quality directly influences the health and growth rates of aquatic organisms. Water quality sensors are crucial instruments in aquaculture for the ongoing or occasional assessment of important environmental factors in ponds, tanks, and cages. These sensors enable real-time monitoring of critical water quality parameters like Dissolved Oxygen, Temperature, pH, Salinity, and ammonia. The following are the types of water quality sensors commonly used in aquaculture systems.

**Temperature sensors** Fishes have their respective specific temperature requirements, which vary according to the species. Temperature sensors often use thermocouples or thermistors to continuously measure water temperature, and these data are used to maintain the water temperature within an optimal range.

**Dissolved oxygen (DO) probes** Dissolved oxygen is essential for the survival of fish and other aquatic species, and the sensors that measure DO use optical or electrochemical techniques. A typical DO sensor allows farmers to read the existing DO level in the system and ensure that the oxygen levels are within the optimal range.

**pH Sensors** Like temperature, pH requirements vary from species to species, and when there is a shift in the optimal range fishes become stressed and the growth rate drops. The pH sensors use hydrogen ion concentration in liquids to determine the alkalinity or acidity level through the use of pH sensitive glass electrode, and the voltage produced will be proportional to the pH of the solution. The difference between the measuring electrode and the reference electrode represents the acidity or alkalinity.

**Turbidity Sensor** The presence of suspended particles like organic matter, algae, or debris results in water becoming turbid. High turbidity can reduce light penetration and affect the phytoplankton growth, thereby decreasing the availability of dissolved oxygen. Turbidity sensors use optical techniques, such as an infrared transmitter to send light through the liquid, and the receiving module measures the transmitted light. The intensity of transmittance is determined by the suspended particles.

**Total Dissolved Solids Sensor** These sensors measure the concentration of dissolved inorganic salts and organic matter in water by measuring its electrical conductivity, which is expressed in ppm or mg/l. These sensors measure electrical conductivity, and higher ion concentration increases conductivity, resulting in higher TDS. A typical TDS sensor has a waterproof probe with two metal electrodes and an analogy signal converter module.

**Conductivity Sensor arrays** A critical tool in modern intensive aquaculture, where real-time monitoring of water quality is measured, and data are provided immediately. IoT-enabled systems combine conductivity, pH, temperature and Dissolved oxygen sensors with data transmitted via IoT to cloud servers for remote monitoring.





Figure 1: Sensor-Based Device for Monitoring Physiological and Environmental Parameters. (Mark Newton et. al 2012)

### Biological & Behavioural Sensors in Aquaculture

Fish behavioural sensors offer use beyond the conventional water quality assessment methods used as of offers quick and immediate insights into fish health stress and water quality. The biological indicators of stress like growth performance biochemical indicators, respiration and feed behaviour and fluctuations in these signals the initial phase of illness, water quality inadequacy and feed rejection. These enable farmers to ensure that culture is sustained through necessary action. These are essential for precise agriculture, allowing for prompt identification of stress illness hunger or unusual behaviour while enhancing feeding monitoring growth, and timing harvests. These modern nonintrusive sensors use computer vision stereo-imaging and an AI-driven machine learning model to estimate fish size weight and stress.

### Advanced Chemical Sensors in Aquaculture

Advanced chemical sensors are sophisticated monitoring tools which are capable of detecting the slightest changes in the water with high precision. When conventional sensors measure general parameters. The advanced sensors measure and identify unionized ammonia spikes in ammonia and nitrite also other toxicants even in low concentrations. These are useful in intensive systems like recirculatory aquaculture systems, where fish are

grown in high intensity. These sensors support early warnings in aquaculture and improve biosecurity.

### Smart & Wireless Sensors

Intelligent and wireless sensors facilitate automation and precision aquaculture, featuring automatic aeration management optimized feeding mechanisms, and effective water recycling in recirculating aquaculture systems. Their implementation boosts efficiency lessens resource waste decreases ecological effects and enhances overall sustainability rendering them vital elements of contemporary and smart aquaculture methods.

### Incorporation of Automation and AI in Aquaculture

The combination of automation and artificial intelligence (AI) with sensor-based monitoring systems has revolutionized conventional aquaculture into an intelligent and precision-oriented production system. Real-time information gathered from sensors monitoring water quality, biological factors, and behaviour functions as inputs for automated decision-making tools powered by AI.

**Automatic feeding systems** utilize sensor information regarding fish behaviour appetite, and biomass to adjust the quantity and timing of feed dynamically. This reduces overfeeding enhances feed conversion efficiency lowers nutrient waste and decreases water pollution.

**Smart aeration control systems** operate aerators only when dissolved oxygen (DO) levels fall below predefined thresholds. Such demand-based aeration conserves energy maintains optimal oxygen levels and prevents stress-related mortality in fish and shrimp.

**Predictive analytics and AI** models examine past and current data to anticipate disease outbreaks, dangerous changes in water quality and environmental stress incidents. Timely alerts enable



farmers to adopt proactive management approaches instead of response-based remedies.

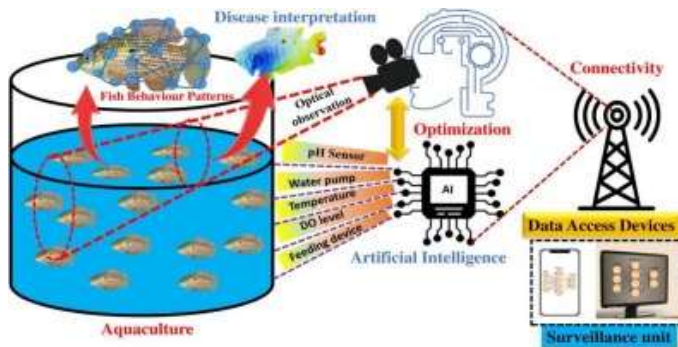


Figure 2: AI-Based Smart Aquaculture Monitoring System (Kamlesh Sen et. al 2025)

### Benefits of Sensor-Based Aquaculture

Sensor-based systems provide precise control over culture conditions and support data-driven decision making. The key parameters are continuously monitored and this enables early detection of unfavourable quality changes in water, thereby causing stress disease risk and mortality. Application of sensors in aquaculture has proven to be fruitful as the feeding efficiency is improved and better feed conversion is achieved. Sustainability of the environment is enhanced by the reduction of water discharge improved water recycling and decreased reliance on chemicals and antibiotics.

### Challenges and Limitations in Aquaculture

Aquaculture plays a vital role in meeting the growing global demand for nutritious food yet its sustainability is influenced by several biological technological and socioeconomic challenges. One of the most persistent issues in intensive farming systems is the deterioration of water quality caused by high stocking densities excess feeding and the accumulation of metabolic waste. Poor water conditions often result in stress disease outbreaks reduced growth and increased mortality.

Health management and biosecurity also remain major concerns. Intensive culture conditions allow pathogens to spread rapidly and inadequate

biosecurity measures often lead to increased reliance on antibiotics and chemicals. This not only raises production costs but also contributes to antimicrobial resistance and environmental contamination.

Although sensor technologies have made intensive aquaculture more manageable and reduced manual monitoring efforts, they also have certain limitations. Issues such as improper calibration poor maintenance, sensor drift over time, and the need for multiple sensor units to monitor different parameters can affect accuracy and efficiency. In addition, high installation costs power supply requirements and the need for technical expertise can limit adoption particularly among small-scale farmers.

Despite these challenges sensor-based monitoring remains a valuable tool for maintaining water quality and supporting better farm management. Continuous advancements in sensor design data integration and maintenance practices are gradually addressing many of these limitations making these systems more reliable affordable and accessible for the aquaculture sector.

### Future Trends in Aquaculture

Aquaculture is anticipated to assume a more significant role in fulfilling global food needs, with its future advancements influenced by technology sustainability and climate adaptability. A significant trend is the growth of precision and smart aquaculture which incorporates sensors automation Internet of Things and artificial intelligence (AI) to facilitate real-time monitoring predictive decision-making and effective farm management. Furthermore, practices that are climate-smart along with digital traceability and Eco certification will gain greater prominence, safeguarding environmental protection food safety and consumer trust. In general, these trends seek to enhance aquacultures efficiency resilience and sustainability.



## Conclusion

Technology reliant on sensors has emerged as a fundamental element of contemporary aquaculture providing efficient solutions to the issues linked with intensive aquatic farming. By facilitating ongoing and immediate observation of water quality biological reactions and fish activities, sensors aid in the accurate management of essential factors like dissolved oxygen, temperature, pH, salinity, and nitrogenous waste. Combining sensors with automation and artificial intelligence significantly improves operational efficiency by optimizing feeding enabling intelligent aeration and facilitating predictive disease management. Despite the presence of challenges like elevated upfront expenses, intricate technology and the requirement for qualified staff continuous technological progress and declining sensor prices are anticipated to enhance accessibility and acceptance. Anticipating the future, the ongoing advancement of intelligent data-oriented, and climate-adaptive aquaculture systems will be essential for enhancing productivity animal wellbeing and ecological sustainability. In general sensor-driven aquaculture offers a hopeful avenue for fulfilling future worldwide seafood needs responsibly and sustainably.

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# Bihar 2047: How Rural Transformation Will Shape the State's Future

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The developmental trajectory of Bihar is fundamentally anchored in the transformation of its rural economy. With a predominantly rural demographic structure and a historical dependence on agriculture, Bihar's pathway toward India's Vision 2047 must necessarily be rural-centric, productivity-driven, and institutionally robust. This paper advances the argument that rural transformation in Bihar is not a peripheral policy objective but the structural engine of long-term economic modernization. Drawing upon trends in agricultural diversification, rural infrastructure expansion, women-led collective enterprise, digital inclusion, migration dynamics, climate resilience strategies, and value-chain development, the article situates Bihar's rural economy within broader frameworks of structural transformation and inclusive growth. It contends that by integrating productivity enhancement with institutional reform and demographic capitalization, Bihar can transition from a low-income agrarian system to a diversified rural growth model by 2047.

## 1. Introduction: Reframing Bihar's Development Narrative

Bihar's economic history has often been narrated through the lens of constraints—high population density, fragmented landholdings, flood vulnerability, limited industrialisation, and persistent out-migration. However, development economics teaches us that structural transformation is rarely linear; it unfolds through institutional strengthening, sectoral diversification, and infrastructure expansion.

In the context of Vision 2047, Bihar faces a pivotal question: can a predominantly rural state accelerate economic modernization without replicating the environmentally unsustainable urban-centric growth models of the past?

The answer lies in rural transformation that enhances productivity, deepens value addition, strengthens human capital, and embeds sustainability into growth strategies.

Rural Bihar is no longer a static agrarian landscape—it is an evolving socio-economic system undergoing gradual yet significant restructuring.

## 2. Structural Transformation Theory and Bihar's Rural Context

Classical development theory posits that economic growth involves a gradual shift of labour from low-productivity agriculture to higher-productivity manufacturing and services. Bihar's challenge is distinctive: agriculture still absorbs a substantial share of the workforce, while industrial absorption capacity remains limited.

Therefore, the state must pursue a hybrid pathway:

- Enhancing productivity within agriculture
- Promoting agro-industrial linkages
- Expanding rural non-farm employment
- Leveraging demographic advantages

Rather than abandoning agriculture, Bihar must modernize it while simultaneously building complementary rural enterprises.

This integrated structural approach will determine whether the state converges toward national growth averages by 2047.



### 3. Agricultural Diversification and Productivity Enhancement

Agriculture contributes significantly to rural employment but comparatively less to value addition. This imbalance reflects low productivity and limited processing capacity.

#### 3.1 Emerging Diversification Trends

Recent patterns indicate:

- Increasing allocation of land toward horticulture and vegetable cultivation
- Expansion of dairy cooperatives
- Growth of fisheries in water-abundant zones
- Commercialization of makhana and maize

Diversification improves income elasticity and stabilizes rural cash flows. Empirical observations suggest that households engaged in allied activities often exhibit higher income resilience compared to mono-crop farming systems.

#### 3.2 Value Chain Imperative

The central constraint is not merely production volume but inadequate value capture. Post-harvest losses, insufficient cold storage, and fragmented supply chains erode farmer profitability.

By 2047, rural transformation must prioritize:

- Storage infrastructure
- Agro-processing units
- Branding and packaging
- Market intelligence systems

The shift from “production-centric” to “value-chain-centric” agriculture will redefine rural income dynamics.

### 4. Infrastructure Expansion as a Productivity Multiplier

Infrastructure investment in Bihar has yielded measurable multiplier effects.

### 4.1 Road Connectivity and Market Integration

Improved rural connectivity reduces transaction costs and enhances spatial integration with urban demand centers. Lower transport costs increase farm-gate realization prices and incentivize commercial cropping.

### 4.2 Electrification and Productive Capacity

Expanded electricity access has enabled mechanized irrigation, small-scale agro-processing, rural retail expansion, and digital service delivery. Electrification functions not merely as a welfare indicator but as a production enabler.

### 4.3 Digital Inclusion and Information Efficiency

Digital penetration enhances information symmetry in rural markets. Farmers with access to real-time pricing and government platforms demonstrate greater bargaining power and reduced dependence on intermediaries.

By 2047, digital infrastructure may prove as transformative for rural Bihar as irrigation canals were in earlier agrarian revolutions.

## 5. Women-Led Collectives: Social Capital as Economic Capital

The expansion of self-help groups represents a structural shift in rural socio-economic architecture.

Women-led collectives perform three critical functions:

1. Financial intermediation
2. Enterprise incubation
3. Social empowerment

Participation in collective micro-enterprises correlates with improved household savings behaviour, diversified income sources, and enhanced decision-making capacity.

The long-term macroeconomic implication is profound: when half the rural population becomes



economically active, aggregate productivity expands structurally.

Vision 2047 must therefore treat gender inclusion not as a welfare policy but as a growth strategy.

### **6. Migration Dynamics: Transitional Phenomenon or Structural Feature?**

Bihar has historically experienced high out-migration due to limited industrial employment. Remittance inflows have supported rural consumption and housing investments.

However, remittance-led consumption without local production expansion can create structural dependency.

The emerging rural entrepreneurial ecosystem—comprising agro-processing units, service enterprises, and digital startups—suggests the possibility of gradual endogenous employment creation.

The long-term objective should be balanced mobility, where migration reflects opportunity optimization rather than distress-driven displacement.

### **7. Climate Resilience and Ecological Sustainability**

Bihar's agrarian system is highly climate-sensitive. Floods in northern districts and periodic drought stress in southern regions impose significant productivity volatility.

Sustainable transformation requires:

- Climate-resilient seed varieties
- Micro-irrigation expansion
- Watershed development
- Renewable energy integration
- Risk-mitigation through crop insurance

By embedding climate resilience within agricultural planning, Bihar can reduce systemic vulnerability and enhance long-term income stability.

### **8. Demographic Dividend and Skill Alignment**

Bihar possesses one of India's youngest populations. This demographic composition presents a time-sensitive opportunity.

Without adequate skill formation, demographic advantage can transform into unemployment pressure.

Strategic interventions must include:

- Agribusiness training
- Rural logistics management
- Digital entrepreneurship education
- Technical skill development

Human capital formation is the decisive variable in determining Bihar's 2047 trajectory.

### **9. Institutional Architecture and Governance Efficiency**

Sustainable transformation is contingent upon institutional credibility.

Key priorities include:

- Transparent fund allocation
- Data-driven monitoring systems
- Strengthening Panchayati Raj governance
- Public-private collaboration in rural infrastructure

Institutional efficiency reduces leakages and enhances multiplier effects of public investment.

Rural transformation is not merely economic reconfiguration; it is institutional modernization.

### **10. Scenario Projection: Bihar in 2047**

If structural reforms continue consistently, Bihar's rural economy by 2047 may exhibit:

- Increased per capita rural income
- Enhanced agricultural value addition



- Expanded rural non-farm employment
- Reduced poverty incidence
- Digitally integrated villages
- Gender-balanced economic participation

This transformation would signify convergence toward a diversified and resilient economic model.

### **Conclusion: Rural Renaissance as Bihar's Defining Century Project**

Bihar's developmental destiny will not be written in metropolitan corridors but in its villages.

The transition from subsistence agriculture to diversified, value-driven, climate-resilient rural production represents the central axis of Bihar's future.

Vision 2047 demands more than incremental improvement; it requires structural recalibration—enhancing productivity, empowering women, institutionalizing transparency, capitalizing on demographic potential, and embedding sustainability within economic strategy.

If these dimensions converge coherently, rural Bihar can evolve from a historically constrained economy into a model of inclusive rural modernization.

The transformation is underway. The decisive challenge is sustaining momentum across decades. By 2047, Bihar's villages could stand not as symbols of economic vulnerability but as exemplars of structural resilience and developmental foresight.

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# Health Benefits of Fruits and Vegetables in Human Life

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In our country, fruits are cultivated on 7.1 million hectares of cultivable land, while vegetables occupy about 10 million hectares. (Source: Ministry of Agriculture and Farmers Welfare).

In the year 2023–24, fruit production reached 114.51 million tons, whereas vegetable production was about 219.67 million tons. (Source: National Horticultural Board, 2014).

For maintaining good health, the human body requires essential nutrients such as vitamins, proteins, minerals, and carbohydrates. Fruits and vegetables are rich sources of these nutrients. According to the Indian Council of Medical Research (ICMR), New Delhi, a balanced diet should include at least 120 g of fruits and 280 g of vegetables per person per day.

In general, our daily diet often lacks sufficient calories, vitamin A, and vitamin B. The regular consumption of fruits and vegetables helps meet these requirements.

Because of their richness in vitamins and minerals, fruits and vegetables are rightly known as “protective foods.”

## Classification of Major Fruits and Vegetables Based on Nutritional Value

Fruits and vegetables are rich in essential nutrients required for maintaining health and preventing diseases. Based on their nutritional levels, they can be classified as follows:

### 1. Rich in Vitamins

Vitamins are essential for maintaining overall health. In a balanced diet, vitamins **A, B, C, D, and E** are particularly important. Among these, **vitamins A, B, and C** are abundantly found in fruits and vegetables.

#### (i) Vitamin A

- **Functions:**

- Supports balanced growth
- Aids in reproduction
- Prevents eye diseases such as night blindness
- Helps in wound healing

- **Sources:** Mango, Papaya, Dates, Spinach, Coriander, Fenugreek, Mustard leaves

#### (ii) Vitamin B1 (Thiamine)

- **Functions:** Prevents diseases such as Beriberi, paralysis, and sore throat
- **Sources:** Cashew, Banana, Papaya, Litchi, Peas, Carrot, Garlic

#### (iii) Vitamin B2 (Riboflavin)

- **Functions:** Prevents weight loss, loss of appetite, and related disorders
- **Sources:** Green leafy vegetables, Bael, Papaya, Pineapple, Pomegranate



### (iv) Vitamin C (Ascorbic Acid)

- **Functions:** Protects against scurvy, arthritis, and infections
- **Sources:** Barbados cherry, Aonla (Indian gooseberry), Guava, Green chillies, Tomato

### 2. Rich in Carbohydrates

Carbohydrates are the primary source of energy for the body.

- **Sources:** Apricot, Dates, Gooseberry, Potato, Custard Apple

### 3. Rich in Proteins

Proteins play a crucial role in body building and are especially important during youth.

- **Sources:** Walnuts, Jackfruit, Peas, Indian beans

### 4. Rich in Minerals

Minerals are vital for growth, development, and the smooth functioning of body systems.

#### (i) Calcium (Ca)

- **Functions:** Prevents rickets in children, reduces irritability, and strengthens bones
- **Sources:** Litchi, Gooseberry, Banana, Bael, Fenugreek, Radish leaves

#### (ii) Iron (Fe)

- **Functions:** Essential for the formation of red blood cells
- **Sources:** Gooseberry, Dates, Cashew, Coriander leaves

#### (iii) Phosphorus (P)

- **Functions:** Ensures smooth functioning of body tissues, aids in fatty acid transport
- **Sources:** Cashew, Walnut, Litchi, Banana, Spinach, Cowpea

### 5. Rich in Fats

Fats serve as a concentrated source of energy. Fruits generally contain more fat compared to vegetables.

- **Sources:** Walnut, Almond, Cashew

### 6. Rich in Dietary Fiber

Fibers, particularly abundant in leafy vegetables, aid in digestion and overall gut health.

- **Sources:** Guava, Banana, Grapes, Mustard leaves, Spinach

Importance of Vegetables and Fruits in Human Diet

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### 1. Nutrient-Dense Foods

- **Essential Micronutrients:** Packed with vital vitamins (A, C, E, K, and B group) and minerals like potassium, magnesium, iron, and calcium that support key bodily processes.
- **Fiber Content:** Promotes digestive wellness, aids in regularity, and helps reduce cholesterol levels.
- **Natural Compounds:** Includes powerful antioxidants such as flavonoids, carotenoids, and polyphenols that help neutralize free radicals.

### 2. Preventing Illness

- **Heart Health:** Consistent consumption helps lower the chances of heart attacks and strokes by improving cholesterol levels and reducing blood pressure.
- **Cancer Defence:** Specific nutrients (like sulforaphane in broccoli and lycopene in tomatoes) show potential in fighting cancer cells.
- **Managing Diabetes:** High fiber and low sugar impact help stabilize glucose levels.



- **Strong Bones & Sharp Vision:** Nutrients like vitamin K, calcium, and eye-protective compounds (lutein and zeaxanthin) contribute to skeletal strength and visual clarity.

### 3. Immune Boosting

- **Immunity Enhancers:** Vitamin C and beta carotene strengthen immune responses and guard against infections.
- **Pandemic Insights:** Studies during COVID-19 highlighted that a diet rich in fruits and vegetables improves immune resilience.

### 4. Functional Nutrition

- Many fruits and vegetables offer therapeutic benefits beyond basic nourishment.
- **Examples Include:**
- **Grapes:** Contain resveratrol, beneficial for heart function
- **Carrots:** Loaded with beta carotene, supporting eye health
- **Beetroot:** High in nitrates, which enhance circulation

### 5. Global Nutrition Challenges

- **WHO Guidelines:** A minimum of 400g of fruits and vegetables daily is advised, yet many populations fall short.
- **Impact in Developing Nations:** Inadequate intake leads to nutrient shortages, contributing to growth delays, iron-

deficiency anemia, and compromised immunity.

### 6. Scientific Backing

- **Research Findings:** Comprehensive studies show that increased fruit and vegetable intake correlates with lower death rates and reduced risk of chronic diseases.
- **Optimal Intake:** Health advantages grow with consumption up to around 800g per day, especially for heart-related benefits.

### Conclusion :

Fruits and veggies are a must in our diets—they don't just fill us up, they keep us healthy in so many ways. Packed with vitamins, minerals, fiber, and all sorts of good stuff, they boost our immune systems and shield our cells from damage. Eating them regularly cuts down your chances of heart problems, diabetes, high blood pressure, obesity, and even some cancers. Plus, they keep your digestion running smoothly and help balance your energy levels.

These days, with cities growing fast, busy lives, and all the processed junk we grab on the go, people are eating way less of them. That's throwing our nutrition out of whack. We need to fix this by starting nutrition smarts right in schools and making sure fruits and veggies are easy to get, top quality, and cheap enough for everyone—through smart government policies and community programs. Teaming up like this will help us all live healthier, smarter, and longer.

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# The Power of the Hive: Exploring the Properties and Uses of Bee Products

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The honey bee, *Apis mellifera*, is a highly social and economically important insect species belonging to the order Hymenoptera. It lives in large, well-organized colonies exhibiting advanced social behavior and division of labour. Honey bees are among the most efficient pollinators of agricultural and wild plants, contributing significantly to global food production and ecosystem stability.

The species undergoes complete metamorphosis consisting of four developmental stages: egg, larva, pupa, and adult. The duration of development varies among castes—approximately 16 days for queens, 21 days for workers, and 24 days for drones. Adult honey bees are typically black and yellow, measuring about 12–15 mm in length. They possess two pairs of membranous wings and a specialized elongated mouthpart called a proboscis, which is adapted for extracting nectar from flowers for honey production.

## Bee products:

1. Honey
2. Bee wax
3. Royal jelly
4. Bee venom
5. Propolis
6. Pollen

### 1. Honey:

- Honey is a sweet, viscous fluid produced by honeybees. Honey by honeybees is collected as nectar from nectaries and is also collected from fruit juice and cane juice.
- Bee draws nectar by its tongue and then it is eliminated by field bees and collected by bee hives. Nectar contains about 20-40% sucrose.

Then further sucrose is converted into glucose and fructose with the action of an enzyme Invertase, Invertase is present in nectar and in the saliva of honey bee. Ripening of honey is done by the action of enzymes and by evaporation of water.

## Properties of honey:

- Fully ripened honey mainly consists of Fructose approx. 41.0%, Glucose approx. 35.0%, Sucrose approx. 1.9%, Dextrins approx. 1.5 %, Minerals approx. 2.0%, Water approx. 17.0%, Undetermined (enzymes, vitamins, pigments etc.) approx. 1.6%. Pigments include: Carotene, Chlorophyll, Xanthophyll. Minerals include: K, Ca, P, Na, Mg, Mn, Cu, S, Si, Fe. Vitamins include: Vit B1(Thiamine), Vit B2 (Riboflavin), Nicotinic acid, Vit K, Folic acid, Ascorbic acid, Pantothenic acid.
- Honey is hygroscopic, viscous fluid, specific gravity of pure honey is 1.35-1.44gms/cc, specific gravity is measure by using hydrometer, Aroma and Flavor is acquired from the nectar of flower, colour of honey depends on the nectar of flower, darker honey has stronger flower and lighter honey has more pleasant smell. Crystallization is a natural property of honey (particularly at low temp.).

## Uses of honey:

- Honey is widely used as a natural sweetener and quick energy source due to its glucose and fructose content. It has antimicrobial, anti-inflammatory, and antioxidant properties, making it useful for wound healing, cough relief, and digestive health. Honey is also used in cosmetics,



pharmaceuticals, Ayurvedic preparations, and various food products.

## 2. Bee wax:

- Bee wax is a natural, edible, and water insoluble substance produced by honeybees, known for its malleability, low melting point (62-65 Degree Celsius) and preservative properties.

### Properties of bee wax

- Beewax is malleable at room temp., it melts into a yellow or white liquid and acts as a thickening agent in creams and lotions, it is protective and waterproof, moisture- locking barrier on skin and protects wood or metal from corrosion. It has natural antibacterial, anti- inflammatory and antiseptic properties. It contains fatty acids and esters that is safe for human consumption.

### Uses of beewax:

- Beewax is used in skincare, cosmetics like: lip balm, lotions, creams, ointments these are used to lock moisture in the skin and soothe skin, used in home care and crafts like: making long burning candle, polish furniture, lubricate wooden drawers and seal jars. It is also used as a food preservative, acts as a coating for cheese, fruits and creates reusable food wraps. Raw, Unrefined wax uses in cosmetics and pharmaceuticals.

## 3. Royal jelly:

- Royal jelly is a nutrient- rich, gelatinous substance secreted by worker bees, known for its potent antioxidant, anti- inflammatory and antimicrobial properties.

### Properties of royal jelly:

- It contains a high amount of nutrients including protein, amino acids, carbohydrates, lipids and vitamins. It reduces oxidative stress and inflammation, helps in antimicrobial and immune system, contains compounds like royalisin and jelleines that possess antibacterial and antifungal

properties, and it helps to regulate hormones, improve skin collagen production and promote tissue repair.

### Uses of royal jelly:

- Used to boost energy, reduce stress, improve mental health, support immune function helps in wound healing and in managing diabetes, treat skin conditions like acne or eczema, reduce signs of aging and helps in lowering cholesterol etc.

## 4. Bee venom:

- Bee venom (apitoxin) is a potent mixture of peptides, enzymes, and amines, used in apitherapy.

### Properties of bee venom:

- It contains components like melittin and adolapin that reduce inflammation and alleviate pain, it has antimicrobial and antiviral properties, it has anticancer potential, melittin can induce cancer cell death, helps in reducing allergy sensitivity to bee stings.

### Uses of bee venom:

- Used to treat joint pain and arthritis, provides potential treatments for parkinson's and alzheimer's diseases, used in cosmetics for anti-aging and helps to treat sciatica, back pain etc.

## 5. Propolis:

- Propolis, or 'bee glue', is a natural resinous mixture produced by bees, renowned for its potential antimicrobial, anti-inflammatory, antioxidant and antiviral properties.



**Properties of propolis:**

- Kills or slows the growth of bacteria, viruses, and fungi (antimicrobial and antiseptic properties), helps to reduce inflammation and oxidative stress, treat skin conditions, enhance the activity of immune cells, such as macrophages and natural killer cells and it is rich in flavonoids and phenolic acids, it is used to treat wounds, burns etc.

**Uses of propolis:**

- Used to treat burns, acne, cold sores etc., used in mouthwashes and toothpaste to control gum disease, dental problem and oral infections, used to relieve symptoms of colds, flu etc., helps in enhancing natural immunity and act as anti-parasitic.

**6. Pollen:**

- Bee pollen, a nutrient –dense mixture of flower pollen and bee secretions, is rich in proteins, amino acids, antioxidants, vitamins and minerals. It is act as a powerful nutritional supplement.



**Properties of pollen:**

- It has high antioxidant activity (protecting against free radicals), it contains over 250 active compounds, including vitamins (A,C,D,E), minerals and amino acids, it has anti-inflammatory, antimicrobial, and potential anti-cancer properties, for bees, it serves as the primary protein source for the colony

**Uses of pollen:**

- Taken to boost energy levels, enhance physical performance, manage stress, manage allergies, improve metabolism, reduce cholesterol support liver function, applied to products for soothing diaper rash or eczema, it has benefits in easing cancer treatment side effects (radiation therapy) and aiding with prostate issues.

**Conclusion:**

Bees are commercially important insects because their products possess significant nutritional and medicinal value. Bee products exhibit antioxidant, anti-inflammatory, and antiviral properties and contain essential vitamins, minerals, and amino acids. They are widely used in wound healing, cholesterol management, immune support, and in reducing certain side effects associated with cancer treatment. Therefore, bee products play an important role in food, medicine, and health industries.

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# Chedi Butta Sarees

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Nowadays the chedibutta sarees are famous for its handly woven mechanism and its unique plant border designs. It was introduced by Saurashtran people who are migrate from Gujarat to south Tamil Nadu (Tirunelveli, Sivaganga and Madurai) in Rani Mangammal period. The speciality of the chedibutta saree is warmth in winter and cool in summer so, it was comfortable for wear. Chedibutta sarees are recognised by GI tags for its uniques handly desings by weavers and affordable in price.

## History

Between 600 and 1000 years ago, the Saurashtra people migrated from Gujarat to Tamil Nadu due to wars. They are known as Tamil Saurashtras. Initially, they settled in Madurai, and later, they spread across all districts of Tamil Nadu. Their presence during the reign of Rani Mangammal is supported by historical charters. They sell the saree with exchange of grains. They also thrived during the periods of the Vijayanagara Empire and the Nayak dynasty. They are all treated as well in Rani Mangammal period. They are renowned as the primary weavers of Chedibutta sarees.

## Production area in Tamil Nadu

These sarees are traditionally produced in the Tirunelveli district, particularly in places like Veravanallur, Puthukudi, Vellankuzhi, Kallakam, and the surrounding areas. They have a high demand in the silk market.

## Geographical Indication (GI)

Tamil Nadu has recently received three new geographical indications, bringing the total count to 58 in the state, making it the state with the highest number of GI tags. These three new additions are Jaderi Namakatti, Kanyakumari Matti Banana, and

Tirunelveli Chedibutta sarees. These tags are issued by the Department of Industry Promotion and Internal Trade, Ministry of Commerce and Industry. The present GI application for Chedibutta saree has been submitted by five weavers' associations:

- Veeravanallur Saurashtra Weavers Cooperative Production and Sales Society Ltd.
- Anna Primary Handloom Weavers Cooperative Production and Sales Society Ltd.
- Mahakavi Bharathi Primary Weavers Cooperative Production and Sales Society Ltd.
- Puthukudi Primary Weavers Cooperative Production and Sales Society Ltd.
- Thanthai Periyar Primary Weavers Cooperative Production and Sales Society Ltd.

## Weaving of Chedibutta Sarees

These sarees are woven using a shuttleless weaving technique. This method, replacing the traditional shuttle drawing, offers high speed, high production, reduces noise, and minimizes material consumption by the machine while enhancing product quality. Chedibutta sarees are woven using 75D art silk and 60S cotton on raised pit looms in Tirunelveli district. The motifs feature bright colours with coloured yarn



woven by hand, without the use of dobby or jacquard attachments. The sarees are woven using fine silk and superior cotton yarn. They measure 1.5 meters in width and 5.5 meters in length.

### **Saree colour with butas**

The name "Chedi" means plant, and "Buta" means border. The border of these sarees showcases various plant and flower designs in eight different colours, with no colour repetition. These sarees should not be embroidered or printed.

### **Fan folding**

Sarees are folded in "Visiri Madippu" (Fan like folding) style, a common practice in Tamil Nadu silk sarees. This folding method makes it easy to wear the saree in less time and gives it an elegant look.

### **Labor requirement**

Weaving a saree requires three labourers.

### **Price of the saree**

In Co-optex, Chedibutta sarees cost around a thousand rupees, and similar prices can be found on other online websites.

### **Eagerness of the people**

Chedibutta sarees are popular due to their high-quality cotton, making them easy to maintain and wear. They are lightweight and breathable, offering coolness in the summer and warmth in the winter. People are eager to buy these sarees due to their unique designs.

### **Conclusion**

Nowadays peoples owing to the old traditional sarees due its unique designs and type of material used. The obtained GI for veeravanallur sarees showed recognition and encouragement for Tamil Saurastran weavers. The Government should provide sufficient schemes and support to the traditional handloom weavers to commercialize the more traditional sarees to present generations.

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