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Biochar Effectiveness in Soil Fertility Enhancement and Crop Production Improvement: A review

ABSTRACT

Biochar, a carbon-rich solid produced through biomass pyrolysis under oxygen-limited conditions, has emerged as a sustainable amendment for improving soil fertility, enhancing nutrient efficiency, and mitigating climate change. This review synthesizes recent advances (2015–2024) on biochar's role in improving soil physicochemical and biological properties and its effects on crop productivity across diverse agro-ecological systems. The findings highlight biochar's potential to increase cation exchange capacity, water retention, and microbial activity while reducing greenhouse gas emissions and heavy metal bioavailability. However, variability in feedstock, pyrolysis temperature, and soil conditions leads to inconsistent outcomes. Integration of biochar with compost, fertilizers, or microbial inoculants shows synergistic effects on yield and soil health. Future research should focus on biochar standardization, long-term field trials, and techno-economic feasibility for climate-resilient agriculture.

KEYWORDS: Biochar, soil fertility, carbon sequestration, crop production

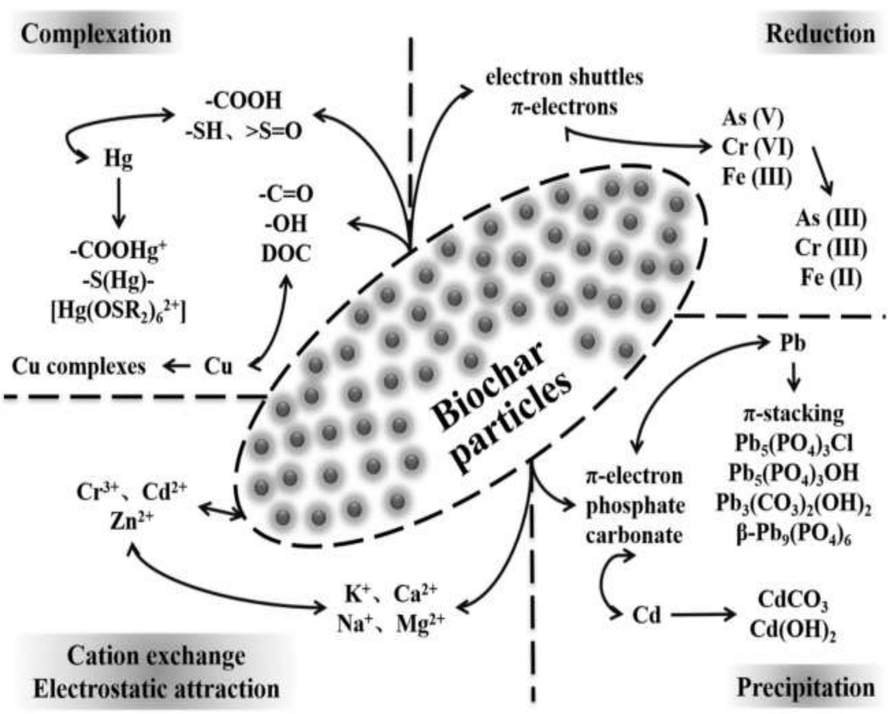

Figure 2. Interaction mechanism between biochar particles and HMs in soil. (Cheng et al., 2020)

1. INTRODUCTION

Soil, as a fundamental resource for agricultural production systems, serves as the primary medium for crop growth and sustains the productivity of plants and animals while maintaining or enhancing water and air quality to support human health and habitation within natural and managed ecosystem boundaries. However, soil quality faces serious threats from anthropogenic contamination, particularly heavy metals, which pose ecological risks to biota and humans. Soil remediation is essential to reduce contamination and mitigate downstream damage, with traditional methods often proving expensive and potentially creating new problems such as fertility loss and soil erosion. Seeking new alternatives, soil stabilization/solidification emerges as a promising technique that offers a potentially less environmentally disruptive and cost-effective approach for future remediation efforts.

Agricultural waste, a long-studied issue, continues to grow with agricultural production, impacting the environment and human health. Despite agriculture contributing significantly to global greenhouse emissions, its solid waste remains a pressing environmental concern. Various uses for agricultural waste exist, including fertilization, adsorption for heavy metal remediation, biochar production, animal feed, and energy sources. The reduction or conversion of agricultural solid waste, such as into biochar, is crucial for environmental health promotion.

Biochar, a carbon-rich by-product of biomass thermochemical conversion, has gained attention for its diverse applications in agriculture, climate, energy, and environment. Its adsorption capabilities stem from surface chemistry, specific area, and pore structure. With properties like surface functional groups and high cation exchange capacity, biochar finds use in soil amendment and sustainable agriculture, contributing to carbon sequestration efforts.

Biochar has emerged as a promising tool for remediating polluted soil and water environments. Several studies have highlighted the effectiveness of biochar in adsorbing heavy metals and organic pollutants from contaminated soil (Cheng et al., 2020; Kong et al., 2013; Fan et al., 2020). Biochar's sorption capacity for organic pollutants is significantly higher than that of soil organic matter, making it a predominant sorptive agent (Kong et al., 2013). Additionally, biochar has been shown to reduce the bioavailability of organic pollutants in soil and water by adsorbing carbonaceous components (Wang et al., 2019). Furthermore, biochar has been found to enhance the remediation of heavy metal-polluted soils, such as cadmium and lead, when modified with thiol compounds (Fan et al., 2020).

In agricultural settings, biochar has demonstrated the ability to improve plant growth and reduce the uptake of heavy metals like cadmium, making it a valuable soil amendment for green agriculture production (Tian et al., 2017). Studies have also indicated that biochar can be used to stabilize both organic and inorganic pollutants in soil, with its effectiveness influenced by factors such as the nature of pollutants, biochar preparation methods, and soil complexity (Kong et al., 2013). Moreover, biochar's wide application in soil remediation is attributed to its pollutant removal capabilities, remediation of contaminated soil, and reduction of greenhouse gas emissions (Yang et al., 2019).

Overall, biochar, due to its low cost, environmentally friendly nature, and diverse active sites, has been increasingly recognized as a versatile material for environmental remediation (Gasim et al., 2022). Its physical structure, characterized by high surface area and porosity, can enhance soil aeration, provide shelter for soil microorganisms, and improve soil quality by providing minerals and water (Su et al., 2022). Biochar has also been explored for its potential in removing contaminants from water, further expanding its applications in environmental remediation (Qiu et al., 2022).

As greenhouse gas emissions pose environmental challenges, biochar offers potential solutions by mitigating climate change, serving as a remediation tool, and supporting bioenergy production. Its impact on soil properties, greenhouse emissions, and achievement of Sustainable Development Goals underscores its importance. Further research into biochar production and application is essential for addressing global challenges and promoting sustainability.

1.1 Conversion of agricultural waste into biochar:

Agricultural solid waste can be converted into biochar through various methods such as hydrothermal carbonization, gasification, and pyrolysis, with pyrolysis being the most common. Pyrolysis involves the thermal decomposition of organic substances at high temperatures under oxygen-absent conditions, producing biochar along with volatile liquids. Slow pyrolysis, conducted at temperatures below 450°C, yields mainly char and takes several hours to complete. Different feedstocks can influence biochar quality and environmental safety, with some potential sources of pollutants needing careful consideration to avoid secondary pollution.

1.2 Biochar elemental composition:

The elemental composition of biochar, including carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, sodium, and silicon, determines its characteristics and applications. Carbon dominates biochar composition, followed by hydrogen and oxygen. The mineral component of biochar, including magnesium, calcium, potassium, and phosphorus, can directly provide mineral nutrients and contribute to heavy metal removal through the formation of metal precipitates. Sulphur-containing biochar are efficient in complex surface formation and heavy metal removal from contaminated water. The porosity and surface area of biochar, influenced by feedstock and pyrolysis conditions, are crucial for pollutant adsorption and water-holding capacity in soil and solution systems. The removal of intrinsic minerals from biomass before pyrolysis can affect biochar properties and production efficiency. Optimizing the type and amount of minerals in biomass is essential for the intended environmental application of biochar.

1.4 Mechanisms of biochar in remediation:

a. **Adsorption:** Biochar's high surface area and porosity facilitate the adsorption of pollutants.
b. **Ion exchange:** Exchangeable functional groups on biochar's surface interact with ions in the soil or water, reducing pollutant concentrations.
c. **Chemical reactions:** Biochar can alter soil and water chemistry, leading to the immobilization or degradation of pollutants (Montgomery et al., 2020).
d. **Microbial activity:** Biochar can enhance microbial activity, promoting the degradation of organic pollutants.

1. **Role of biochar in environmental safety and sustainable agriculture**

- **Soil Health:** Biochar improves soil properties, fertility, water retention, and pH balance, leading to increased microbial activity and nutrient availability.

- **Crop Productivity:** It promotes plant health and productivity through microbial stimulation, water retention, and nutrient availability, contributing to sustainable agriculture (Ramzan et al., 2024).
- **Carbon Sequestration:** Biochar sequesters carbon in soil, mitigating greenhouse gas emissions and climate change while improving soil fertility.

2. **Biochar in plant disease management**
    - Alternative to Chemicals: Biochar offers an eco-friendly alternative to chemical pesticides, promoting soil health and reducing environmental harm.

3. **Mitigating climate change with biochar**
    - **CO2 sequestration:** Biochar contributes to **carbon sequestration**, storing stable carbon forms for hundreds of years (Woolf et al., 2010). It also reduces **greenhouse gas emissions** by decreasing N_2O and CH_4 fluxes from agricultural soils (Cayuela et al., 2014).
    - **Greenhouse gas reduction:** It decreases emissions of methane and nitrous oxide, contributing to overall greenhouse gas reduction.
    - **Long-term carbon storage:** Biochar's stable carbon structure allows for long-term carbon storage in soil, aiding in climate change mitigation efforts.

4. **Environmental safety concerns**
    - **Production process:** Emissions during biochar production and potential ethylene release in soil raise environmental concerns.
    - **Degradation and contaminant release:** Biochar degradation in warm climates and release of contaminants may affect soil health and efficacy.

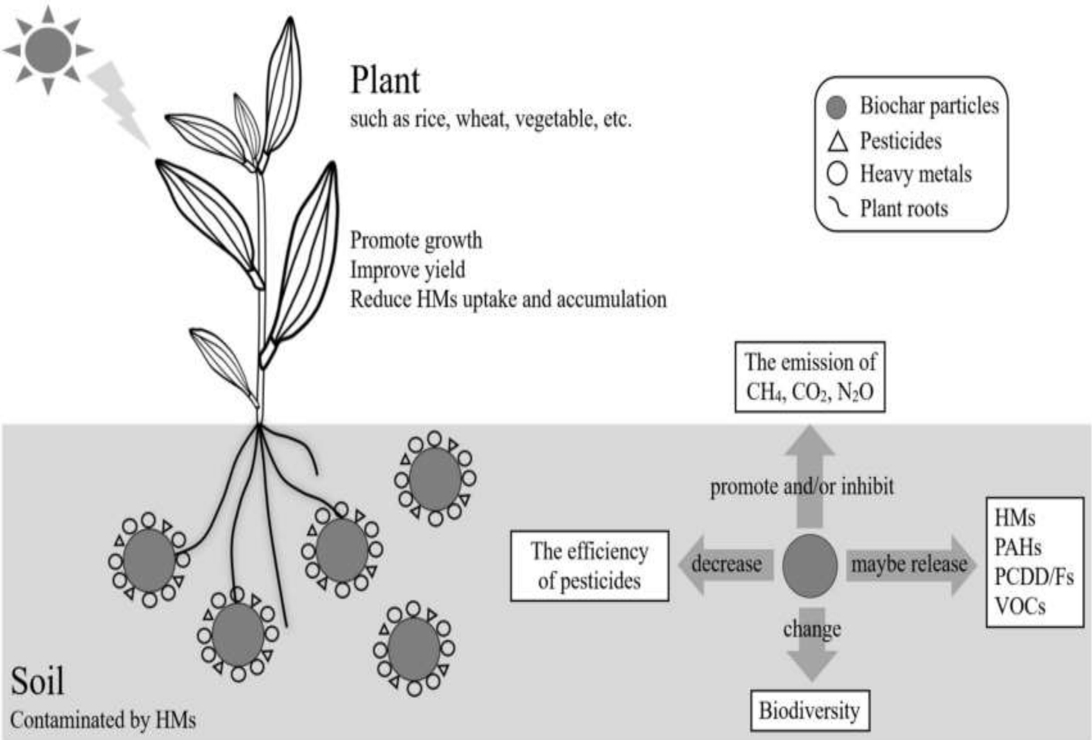

Figure 3. Advantages and disadvantages of biochar in the remediation of soil HM contamination. (Jien & Wang, 2013)

Agricultural waste-derived biochar holds promise for ensuring environmental safety and sustainability. The impact of minerals on biochar attributes is significant, necessitating optimization of mineral content and quantity in biomass for specific environmental applications. Biochar has demonstrated significant advancements in reducing greenhouse gas emissions, minimizing soil nutrient leaching, sequestering atmospheric carbon in soil, enhancing agricultural productivity, and decreasing the bioavailability of environmental contaminants. Widely recognized for its remediation capabilities, biochar plays a crucial role in climate change mitigation and bioenergy production while improving plant health and crop productivity upon incorporation into the soil.

Contrary to popular belief, biochar products are not structurally homogeneous materials but encompass a diverse array of heterogeneous elements and chemical structures. This misconception often stems from the variation in parent biomass and pyrolysis conditions, resulting in a spectrum of particle sizes, electrical conductivities, and surface areas among different biochar products. Biochar products offer environmental benefits by establishing a connection between charred biomass and soil, thereby contributing to environmental management and technology, including applications in land administration. Perceived advantages include increased soil fertility and crop yield. The paper evaluates the suitability of biochar products for environmental management and technology, assessing their impacts on soil and soil biota alongside various production techniques and associated manufacturing costs at different scales.

Soil, as a fundamental resource for agricultural production systems, serves as the primary medium for crop growth and sustains the productivity of plants and animals while maintaining or enhancing water and air quality to support human health and habitation within natural and managed ecosystem boundaries. However, soil quality faces serious threats from anthropogenic contamination, particularly heavy metals, which pose ecological risks to biota and humans. Soil remediation is essential to reduce contamination and mitigate downstream damage, with traditional methods often proving expensive and potentially creating new problems such as fertility loss and soil erosion. Seeking new alternatives, soil stabilization/solidification emerges as a promising technique that offers a potentially less environmentally disruptive and cost-effective approach for future remediation efforts.

FUTURE SUGGESTIONS:

The possible hazard of biochar

While biochar has significant benefits for cleaning up soil pollutants, enhancing soil quality, raising agricultural yields, and lowering greenhouse gas emissions, these studies are all the effects of biochar on soil for short term, but it is effect in long terms are largely unknown. Therefore, more attention should be made to the long-term impacts and risk assessment of biochar on soil to maximise its utilisation and minimise any potential dangers.

Research has indicated that while using biochar enhanced crop output and soil quality, it also doubled the growth of weeds and decreased the effectiveness of herbicides. Since herbicide efficacy must be reduced, more herbicides must be used, which could raise the residue content of herbicide in the soil and result in more severe pollution. Furthermore, biochar which is primarily made from agricultural waste may naturally include heavy metals and, if it finds its way into the soil, may unleash other pollutants.

Biochar would degrade physically,

chemically, and biologically because of weathering and age. Ultimately, it would create colloids, nanoparticles, and smaller pieces that change the soil's microbial population. Further research is still required to fully understand the relationship between these biochar constituents and soil, as well as the internal mechanisms underlying microbial transformation and geochemical circulation.

CONCLUSION:

This article aims to provide a thorough understanding of the role of biochar in remediating polluted soil and water environments, emphasizing its effectiveness, challenges, and prospects for future application and research. By harnessing the unique properties of biochar, we can move towards more sustainable and environmentally friendly solutions for combating soil and water pollution.

Biochar has gained attention not only for its ability to remediate polluted environments but also for its capacity to enhance soil fertility. Here's how biochar achieves this:

1. Improved soil structure: Biochar is porous and has a large surface area, which helps in improving soil structure (Lehmann et al., 2021). It creates pore spaces in the soil, allowing better aeration and water retention. This enhances root growth and facilitates the movement of nutrients to plant roots (Ali et al., 2025).

2. **Increased water retention**: The porous structure of biochar enables it to hold water like a sponge. This improves water retention in the soil, especially in sandy or degraded soils prone to drought. Plants have better access to water, reducing water stress and improving overall plant health.

3. Nutrient Retention and Availability: Biochar has a high cation exchange capacity (CEC), meaning it can attract, retain, and exchange positively charged ions like calcium, magnesium, and potassium. This prevents leaching of nutrients from the soil, making them more available to plants over time. Additionally, biochar can absorb and store nutrients, releasing them gradually as needed by plants.

4. Microbial activity enhancement: Biochar provides a habitat for beneficial soil microorganisms. Its porous structure and high surface area offer refuge and nutrients for microbes, promoting their growth and activity. Healthy soil microbiota contributes to nutrient cycling, organic matter decomposition, and disease suppression, ultimately enhancing soil fertility.

5. Carbon sequestration: Biochar is a stable form of carbon that can persist in the soil for hundreds to thousands of years. By incorporating biochar into soil, carbon is sequestered from the atmosphere, contributing to climate change mitigation. Additionally, the presence of biochar in soil can stimulate the formation of stable soil organic carbon, further enhancing soil fertility and resilience (Kirova N, 2025).

6. pH regulation: Depending on its source material and production conditions, biochar can have varying effects on soil pH. Generally, biochar tends to be neutral to slightly alkaline, which can help to buffer acidic soils. This pH regulation can create more favourable conditions for nutrient uptake by plants and improve overall soil fertility.

In summary, biochar enhances soil fertility through improved soil structure, increased water retention, nutrient retention and availability, stimulation of microbial activity, carbon sequestration, and pH regulation. These combined effects contribute to healthier and more productive soils, supporting sustainable agriculture and ecosystem health.

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Next-Generation Flavonoids: Natural Bio-regulators for Plant Defense, Growth and Environmental Resilience

Abstract

Flavonoids are among the most diverse and physiologically significant groups of plant secondary metabolites. These polyphenolic compounds arise from the phenylpropanoid pathway and have various functions in plant physiology that extend well beyond pigmentation. Flavonoids represent central links between growth, defence and adaptation to environmental challenges by resulting from the integration of metabolic, hormonal and signalling pathways. Flavonoids also, represent some of the most effective antioxidants and UV links that help protect plant tissues against oxidative and photochemical damage. The complexity of flavonoids signalling is demonstrated in their role as auxin transporters, signalling upon abiotic and biotic stress, and in rhizosphere communication. This article provides current synthesis of knowledge about molecular and physiological roles of flavonoids and contributions of flavonoids biotic defence (pathogens and herbivores) and abiotic resilience (drought, salinity, and thermal stress).

1. Introduction

Plants, as organisms that lack physical movement, are always interacting with their environment, which is often compounded by multiple abiotic and biotic stressors.

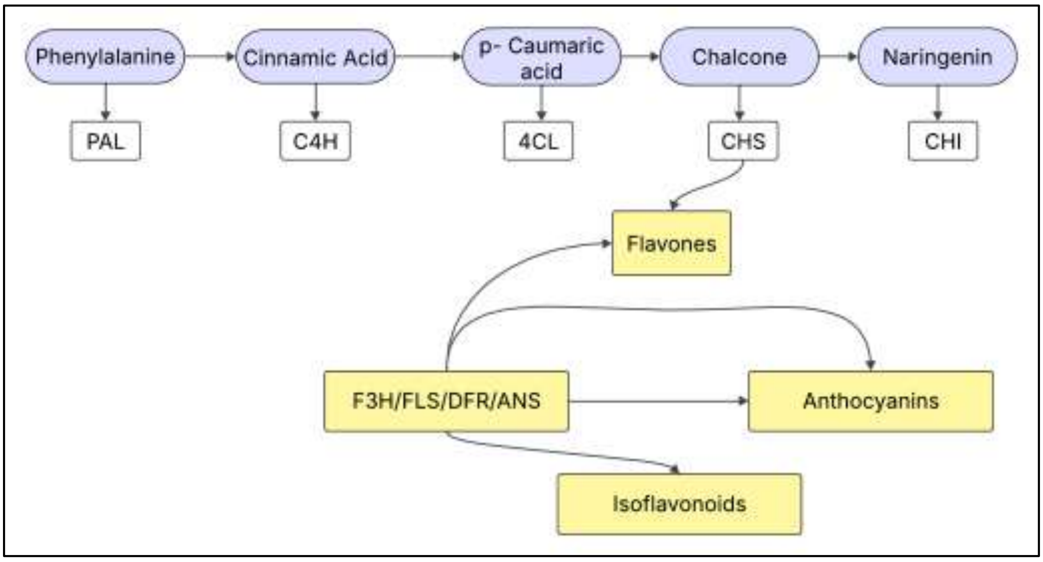

Figure 1. The phenylpropanoid pathway leading to flavonoid biosynthesis in plants

(Abbreviations- PAL: Phenylalanine Ammonia-Lyase, C4H: Cinnamate 4-Hydroxylase, CL: 4-Coumarate:CoA Ligase, CHS: Chalcone Synthase, CHI: Chalcone Isomerase, F3H: Flavanone 3-Hydroxylase, FLS: Flavonol Synthase, DFR: Dihydroflavonol 4-Reductase, ANS: Anthocyanidin Synthase)

Plants consistently face increased ultraviolet (UV) radiation, changing temperature, extreme drought, salinity, nutrient deficiency, as well as infection by pathogens, which consistently threatens plant survival and yield. Plants have evolved to these stresses by developing complex biochemical and molecular systems for perception, signalling, and response. Secondary metabolites, especially flavonoids, play important roles in physiological stability and adaptive performance (Falcone Ferreyra *et al*., 2012; Treutter, 2005). More than 9000 unique structures of flavonoids exist in the plant kingdom. While these flavonoids are generally classified into subgroups like flavones, flavonols, flavanones, flavanols, isoflavones, and anthocyanins (Panche *et al*, 2016), these compounds include many different biological functions. Flavonoids typically accumulate in the epidermal cells, trichomes, vacuoles or root exudates of plants and function in several biological functions ranging from antioxidant stabilization, UV protection, hormonal regulation to regulating plant-microbe interactions (Agati *et al*., 2012; Weston & Mathesius, 2013). A comprehensive understanding of the molecular and ecological dynamics of flavonoid function, therefore, provides a basis to rethink crop management approaches based on climate unpredictability. This article elucidates the biochemical multi-functionality of flavonoids, investigates their interrelated roles as multifunctional regulators of defense, growth, and response to the environment, which allow for the sustainable and resilient agricultural sought in today's constantly changing climate.

2. Multifunctional Roles of Flavonoids in Plant Physiology

Flavonoids have a multitude of physiological functions including acting as antioxidants and antimicrobial agents, regulating processes of growth driven by hormones, promoting tolerance to drought, salinity, and temperature stress, and facilitating plant-microbe interactions in the rhizosphere. All of these functions work together to make them important metabolic regulators which connect plant growth to environmental adaptation.

3. Flavonoids as Modulators of Light Perception

Sunlight is both a provider of energy, and potential form of oxidative damage. Flavonoids act as photo-protective agents in plants, absorbing UV-B radiation while allowing just the same visible light needed for photosynthesis to pass through (Agati *et al*., 2012). This combination keeps plants from sustaining injurious photo-oxidation and controlling the expression of UV responsive genes. Flavonoids act as biochemical filters, regulating redox homeostasis and control signalling by photoreceptors so plants remain photosynthetically efficient under normal conditions, while facing intense light quantities.

4. The Role of Flavonoids in Plant Immunity

Although plants do not have the ability to form mobile immune cells, they develop complex defenses based off chemical signalling. Flavonoids also help facilitate induced systemic resistance (ISR), and systemic acquired resistance (SAR); for example, they notify plants to activate enzymes such as peroxidase or phenylalanine ammonia-lyase (Treutter, 2005). Flavonoids also accumulate rapidly at sites of infection as phytoalexins, which inhibit both bacterial and fungal growth.

5. Root Exudation and Rhizospheric Communication

Flavonoids play important roles coordinators of root-microbe signalling, especially in legume-rhizobial symbiosis, where they induce the expression of bacterial nod genes and ultimately promote the establishment of nitrogen-fixing nodules (Weston & Mathesius, 2013). Flavonoids assist plants in the establishment of mycorrhizal colonization that can improve nutrient acquisition and facilitate positive plant-soil feedbacks. This dimension of plant-microbe interaction, usually below-ground, is a type of biochemical net-working, where the flavonoids can act as signalling currencies, potentially promoting soil biodiversity and plant resilience.

6. Adaptation to Abiotic Stress

Under environmental stress (e.g., drought, salinity, and temp), flavonoids function as molecular antioxidants that scavenge reactive oxygen species (ROS), stabilize membranes, and protect other cellular macromolecules (Nakabayashi *et al*., 2014). They play roles in regulating stomatal conductance and osmolytes accumulation, which help plants save water and facilitate photosynthesis. Once again, within the context of their ability to modulate redox, flavonoids are thought to provide a way for plants to buffer against changing and variable abiotic and biotic conditions.

7. Pigmentation and Ecological Function

Anthocyanin, a more evolved class of flavonoids, contribute towards the reds, purples, and blues of flowers and fruits, which add to the aesthetic value of the plant. However, the evolutionary advantage of these pigments also rests in their photo-protective and ecological signalling properties in their attraction of pollinators, deterring herbivores, while protecting cells from oxidative damage induced by UV light (Gould, 2004). Thus, pigmentation is a beautiful example of how biochemical-based adaptation aligns with ecological function.

8. Biotechnological and Agricultural Implications

Newly discovered ways of using the potential of flavonoids for better crops and a more sustainable agriculture have been the main subject of the recent advances in plant biotechnology. To this end, genetic and metabolic engineering techniques are being applied for the production of flavonoids that are more abundant and their use in the development of such crops that exude the ability to withstand the stress of drought, salinity, and other harsh conditions, nutrient uptake efficiency, and overall plant strength (Pandey *et al*., 2021).

9. Conclusion

For all their diversity and complexity, flavonoids stand out as the most versatile secondary metabolites. They do so by integrating defence, signalling, and adaptation into a unique structural and biochemical framework. Their ability to manage oxidative stress, the role in mutualism with plants, and the provision of better growth conditions named them as the major evolutionary players. With a better understanding of how the plant interacts with the environment, modern agriculture has all the more reason to go for nature-inspired innovations, where the resilience and sustainability of the crops are in sync with the biochemical creativity that has been honed over millions of years.

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SMART FARMING THROUGH IPM AND IT INTEGRATION

Introduction:

Agriculture today faces a dual challenge, ensuring food security for a growing population while minimizing environmental degradation. Pesticide overuse has resulted in pest resistance, ecological imbalance and negative health impacts. Integrated Pest Management (IPM) has emerged as a scientific, eco-friendly and economically viable approach to pest control. At the same time, Information Technology (IT) tools such as remote sensing, artificial intelligence, big data analytics and mobile applications are revolutionizing how IPM is implemented, making farming more precise, resource-efficient and sustainable.

The Green Revolution transformed agriculture with high-yield varieties, fertilizers and pesticides. However, decades of chemical-intensive farming have caused pest resurgence, loss of biodiversity, soil degradation and climate change vulnerabilities. The Food and Agriculture Organization (FAO) emphasizes the urgent need for sustainable crop protection strategies. Integrated Pest Management (IPM) first promoted in the 1960s, combines biological, cultural, physical and chemical control methods to maintain pest populations below economic threshold levels. In parallel, the digital revolution has created opportunities to integrate IT into agriculture, providing farmers with real-time data, predictive analytics and decision-support systems. This convergence of IPM with IT can ensure productivity while safeguarding ecological health. The present era is rightly called the age of information technology (IT). Today IT is widely applied in almost every sector like education, healthcare, business and governance. Agriculture, the backbone of our economy is no exception. By utilizing IT in farming, we can adopt Integrated Pest and Disease Management (IPDM) practices more effectively.

What is Integrated Pest Management (IPM)?

Integrated Pest Management refers to a scientific approach that keeps pest populations below the economic threshold level by harmonizing with the environment. This approach combines mechanical, physical, biological, legislative and chemical methods in a balanced way.

In the past, pest control largely depended on chemical pesticides and even today, they continue to be widely used. However, direct relay on chemicals has resulted in:

- Development of resistance in pests
- Residual pesticide contamination in food crops
- Health hazards for humans due to accumulation of pesticide residues in the body
- Adverse impacts on export of agricultural produce

Importance of IPM in Modern Farming

1. Reduces chemical dependency
   - Encourages judicious pesticide use only when pest levels cross the economic threshold.
   - Gives alternate way to supress pest population without use of chemicals.
   - Decreases residues in food and minimizes farmer exposure.
2. Prevents pest resistance and resurgence
   - Rotating modes of action and combining non-chemical measures reduces resistance development.
3. Environmental protection
   - Promotes biodiversity by conserving natural enemies of pests.
   - Reduces soil and water contamination.
4. Economic sustainability
   - Lowers input costs by integrating biological and cultural practices.
   - Improves net returns through reduced crop losses and higher market acceptance of residue-free produce.
5. Promotes soil and water health:
   - IPM uses cultural control methods, such as crop rotation, balanced fertilization and conservation tillage, which improve soil health and protect against erosion.
6. Conserves biodiversity:
   - By relying on natural predators, parasites and pathogens to control pests, IPM preserves beneficial insect populations and other non-target organisms that are critical for a healthy ecosystem.

Role of Information Technology in Advancing IPM

1. Remote sensing and GIS
   - Satellite and drone imagery detect pest hotspots, crop stress, and disease spread.
   - GIS mapping enables spatial monitoring and targeted interventions.
2. Artificial Intelligence (AI)
   - AI-based pest and disease recognition apps help farmers identify threats instantly through smartphone cameras.
   - Predictive models forecast pest outbreaks using weather and crop growth data.
3. Pest and Disease Forecasting Centre
   - Farmers will enable to know timely dissemination of information about upcoming pest on the basis of weather. Farmers will then be able to act before an outbreak turns severe.
4. Decision support systems (DSS)
   - Mobile and web platforms provide farmers with pest alerts, pesticide rotation guidelines and biological control options.
5. Internet of Things (IoT) and Sensors
   - Farmers can also view images of pests in their larval stages, enabling them to identify harmful insects early and adopt control measures immediately.
   - Farmers can then receive timely advice on the internet about preventive and control measures before the problem enters.
6. Farmer Networks and Extension Apps
   - Social media, WhatsApp groups and mobile apps disseminate IPM advisories rapidly.
   - E-extension services enable continuous farmer–researcher interactions.
7. Promoting Biological Control through IT
   - IT can also spread awareness about beneficial insects that feed on harmful pests.
   - Information such as their availability, usage and benefits can be shared online. This encourages farmers to adopt biological pest control, which is safer, cheaper and environmentally friendly.

Successful Models in India

India has already initiated such IT-based agricultural programs. Successful IPM models in Maharashtra include the government's Crop Pest

Surveillance and Advisory Project (CROPSAPS) and Horticulture Pest Surveillance and Advisory Project (HORTSAPS), which use Information and Communication Technology (ICT) for real-time monitoring of pest and advisories to farmers. Farmer Field Schools (FFS) have also been effective, training farmers in IPM for cotton in the Vidarbha region. Other models incorporate bio-intensive practices, such as using natural predators, border crops and botanicals like neem, and also leverage newer technologies like AI-based pest detection and remote sensing for better decision-making. In Maharashtra some Krishi Vigyan Kendra (KVK) has successfully implemented a Village Linking Program. Computers have been installed in villages to deliver the latest agricultural technologies directly to farmers.

Through such initiatives, even the latest research outputs from agricultural universities can be made accessible to farmers via the internet. Farmers can also interact with experts through online conferences, getting solutions to their farming problems from the comfort of their homes. This saves time, money, and effort.

IPM (Integrated Pest Management) with IT (Information Technology) is no longer just a tool of urban convenience it is transforming rural agriculture as well. By combining traditional wisdom with digital innovation, we can move towards sustainable farming practices where pest and disease management is scientific, eco-friendly and farmer-friendly.

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ARTICLE ID: 04

SEAWEED FAEMING

Summary:
Mariculture, or farming seaweed, is the process of growing seaweed in the ocean or along the coast so that it can be used for many different business purposes. This type of aquaculture doesn't need fertilisers, fresh water, or arable land, which makes it a more environmentally friendly and long-lasting option than traditional aquaculture. Because they are so nutritious, seaweeds are used in many different fields, such as food, cosmetics, fertilisers, and even biofuels. This way of farming also helps the fight against climate change by taking in a lot of carbon dioxide and making marine ecosystems more diverse. People who live near the coast can make money by growing seaweed, which also helps the local economy grow. Because more and more people want it all over the world, it is becoming an increasingly important way to protect the environment and grow food in a way that doesn't hurt the planet.

Introduction:

Agricultural seaweed is the process of growing and harvesting marine algae, which is more commonly known as seaweed, in the ocean or along the coast. It is an old practice that has recently become more important around the world because it is good for the economy and the environment. Seaweeds can be used in many different ways, such as in food, medicine, cosmetics, fertilisers, and even biofuels. Seaweeds are organisms that can be used for many things and are full of vitamins, minerals, and proteins. One of the best things about seaweed farming is that it is a sustainable way to grow food. Seaweeds do not need soil, fresh water, or chemical fertilisers to grow well, unlike crops that are grown on land. They can thrive and help reduce excess nutrients and carbon dioxide in marine environments because they can take in nutrients directly from the ocean. Because of this, growing seaweed is a good thing for the environment because it helps keep the ocean healthy and fights climate change. Also, growing seaweed gives coastal communities, especially those in developing countries, good ways to make money and support themselves. This is good because it gives people a steady source of income, gives them more power, especially women, and helps the economy grow in rural areas. Seaweed farming is a promising way to make sure that people have enough food, that the environment stays in balance, and that growth is sustainable. This is because more and more people around the world want natural and sustainable goods.

Main body:

The first step in seaweed farming is to choose the best coastal areas or shallow marine zones. These are places where the temperature, salinity, light penetration, and water movement are all good for the growth of seaweed. It is very important to choose the right place to find seaweeds because they get their nutrients from the water around them. So, it is best to find them in places that are clean and free of pollution. Kappaphycus and Gracilaria are red seaweeds, Sargassum and Laminaria are brown seaweeds, and Ulva is a green seaweed. These are all examples of species that are grown and harvested in large amounts for commercial use. Each type has its own value in terms of the economy and the environment.

The first step in farming is to get healthy seedlings from hatcheries or the wild. After that, these seedlings are tied to ropes, nets, or bamboo rafts that are anchored in the water to keep them safe. The floating or fixed cultivation methods let the seaweeds get enough sunlight and nutrients while also keeping them safe from seabed predators and strong currents during the growing process. Farmers check their farms for diseases, epiphytes (organisms that grow on seaweed that are not wanted), and changes in water quality on a regular basis during the cultivation period, which usually lasts two to three months.

When the seaweeds are fully grown, they are carefully picked, washed, and then dried in the sun to get rid of some of the water they hold. After it has dried, the seaweed is processed and sold for many different purposes. Seaweed products are widely used in the cosmetics, pharmaceutical, fertiliser, and animal feed industries, as well as in the food industry (as agar, carrageenan, and alginate). In the last few years, seaweed has also gotten a lot of attention as a renewable raw material for making biofuels and as a sustainable food source because it is very nutritious. Both of these uses are becoming more popular.

Seaweed farming is good for the economy and the environment. It helps the atmosphere take in extra carbon dioxide, which slows down climate change. Seaweeds improve the quality of marine water by preventing eutrophication, which is when they take in nitrogen and phosphorus. Seaweed farms also protect marine life and provide places for small fish to breed, which helps keep biodiversity alive.

Using marine resources in a way that is good for the environment is generally what seaweed farming is. The fact that it helps coastal communities keep their jobs and helps keep the ecosystem in balance makes it a good idea for the future of the blue economy.

Conclusion:

In conclusion, seaweed farming is a practice that is both innovative and sustainable, and it offers benefits to both the environment and the economy. Despite the fact that it requires a minimal number of natural resources like land, freshwater, or fertilisers, it offers a source of food, raw materials, and bioproducts that can be replenished over time. The cultivation of seaweed is an important component in the fight against climate change and the preservation of marine ecosystems. Seaweed farming helps to improve water quality and absorb carbon dioxide. In addition to this, it provides coastal communities with opportunities to earn a living, which in turn empowers individuals and helps to support local economies. Seaweed farming has a significant potential to ensure food security, environmental sustainability, and economic development. This potential is exemplified by the fact that the global demand for environmentally friendly and nutrient-dense products is continuing to increase. Through the promotion and expansion of this practice, it is possible to contribute to the creation of a healthier planet and a more sustainable future for future generations.

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SERICULTURE – MULBERRY SEEDLINGS PREPARATION AND NURSERY MANAGEMENT

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Introduction:

Nursery management of mulberry seedlings involves preparing nursery beds, selecting and planting cuttings, and providing consistent care for four to nine months before transplanting them. A healthy nursery ensures high survival rates and vigorous plants for the main field.

Nursery bed preparation

1. **Site selection**: Choose an well-drained, flat piece of land with a reliable water source. The ideal soil is deep loamy type with a pH of 6.5 to 7.0.
2. **Land preparation**: Plough the land deeply (30–40 cm). This improves drainage and aeration.
3. **Bed formation**: Prepare raised beds, typically 15 feet long by 5 ft wide and 15–20 cm high. Leave drainage channels of 25–30 cm width and 15–20 cm depth between beds.
4. **Soil enrichment**: Apply and mix 20 kg of well-decomposed farmyard manure (FYM) into each bed.
5. **Time of Preparing Seedling**- The best time for transplanting cuttings for preparing seedlings is January, February, and march.

Planting material and technique

1. **Select cuttings:** Choose semi-hardwood cuttings (15–20 cm long and 10–12 mm in diameter) from 8–12-month-old mulberry stems. Use a sharp knife or secateurs to make a slanting cut at the base and a straight cut at the top, leaving 3 to 4 healthy buds. Place cuttings in wet gunny bags.
2. **Pre-treatment**: Dip the base of the cuttings in a rooting hormone, like IBA or Azospirillum culture, to encourage faster rooting. Dipping cuttings in a 0.2% Carbendazim (Bavistin) solution can prevent fungal infections.
3. **Planting**: Insert the cuttings into the nursery beds at an angle of 45°, leaving one bud exposed above the soil. Maintain a spacing of about 20 cm between rows and 8–10 cm between cuttings.
4. **Irrigation:** Irrigate the beds immediately after planting to settle the soil.

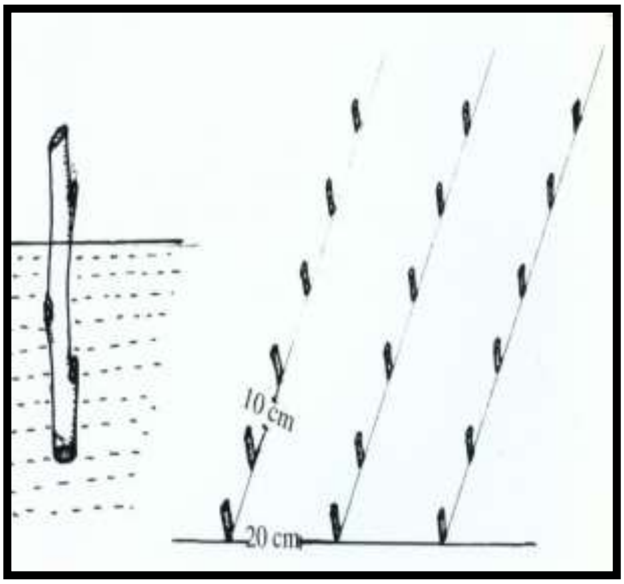
Nursery maintenance

1. **Watering**: Keep the nursery beds moist, but not waterlogged. Irrigate every 4 to 7 days, depending on the soil type and weather conditions. A new method using polythene sheets can help conserve moisture and reduce the need for watering.
2. **Weeding**: Remove weeds by hand weeding, as they compete with the seedlings for nutrients. Weed the beds about 35 - 40 days after planting, and again after 60 days.
3. **Fertilization:** Apply a light dose of fertilizer to boost growth. A common practice is to apply 20 g of urea per square meter after the second weeding. Alternatively, dissolve 250 g of urea or 500 g of ammonium sulfate in irrigation water for each bed after 55–60 days of growth.
4. **Shoot management**: Allow only one vigorous shoot to develop from each cutting. Remove all other smaller shoots.
5. **Pest and disease control**: Monitor for pests and diseases. Common diseases include stem canker, cutting rot, and collar rot, which can be managed with fungicides like Bavistin. Pest infestations can be addressed with appropriate insecticides.

Uprooting and transportation

1. **Timing:** Mulberry saplings are ready for transplanting into the main field after 4 to 9 months, once they reach a height of 90–150 cm.
2. **Preparation:** Two days before uprooting, irrigate the nursery beds thoroughly to make extraction easier and prevent root damage.
3. **Extraction:** Carefully loosen the soil with a spade or pickaxe to a depth of about 30 cm before uprooting each sapling individually.
4. **Handling and transport:** To prevent moisture loss and damage, bundle the saplings and cover them with a wet gunny cloth. Transport them during the cooler hours of the day. It is crucial to plant them in the main field as soon as possible.

Mulbery Cuttings



Mulbery Cuttings Plantation

Mulbery Cuttings in Poly bags

Mulbery Cuttings in Poly bags

Mulbery Cuttings from Raised beds

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ARTICLE ID: 06

Morpho-physiological characterization of *Digloti* (*Litsea salicifolia*); secondary host plant of Muga silkworm (*Antheraea assamensis*): A pre-liminary approach

Abstract

The Muga silkworm (*Antheraea assamensis*), endemic to Northeast India, is renowned for producing the golden Muga silk. However, its dependence on a narrow range of host plants, primarily *Persea bombycina* (Som) and *Litsea monopetala* (Soalu), poses a sustainability concern under changing climatic and ecological conditions. This study presents the first comprehensive evaluation of *Digloti* (*Litsea salicifolia*) as an alternative host plant for Muga culture. Seasonal stability in leaf quality and adaptability of the plant to varied ecological conditions further highlight its suitability. Thus, *L. salicifolia* emerges as a sustainable supplementary host capable of reducing pressure on existing resources and enhancing the resilience of Muga sericulture. Future research should focus on field-level validation, propagation strategies, and agroforestry integration for its large-scale utilization.

Keywords

Muga silkworm, *Antheraea assamensis*, *Litsea salicifolia*, host plant evaluation, silkworm rearing, sericulture, sustainability.

1. Introduction

The Muga silkworm (*Antheraea assamensis* Helfer) is an endemic and economically important sericigenous insect confined to the Brahmaputra Valley of Assam and adjoining regions of Northeast India. Known for its natural golden lustre, Muga silk represents a vital component of the cultural and economic fabric of the region. Traditionally, Muga silkworms are reared on *Persea bombycina* (Som) and *Litsea monopetala* (Soalu), the two primary host plants. However, extensive monoculture practices, deforestation, and climatic fluctuations have led to the degradation of these natural host resources, threatening the sustainability of Muga culture.

Given the increasing ecological stress on conventional host plants, there is an urgent need to explore alternative or supplementary host species that can support the growth and development of *A. assamensis*. Members of the genus *Litsea* (Family: Lauraceae) are widely distributed in Northeast India and possess promising attributes as host plants due to their similar leaf chemistry and adaptability. Among them, *Litsea salicifolia* (locally known as Digloti) has been traditionally identified by local communities as a potential wild host, yet scientific validation has remained scarce.

This study aims to conduct the first developmental and physiological evaluation of *L. salicifolia* as a host plant for Muga silkworms. By assessing morphophysiological parameters of leaf, this research provides foundational data supporting its potential integration into sustainable Muga sericulture systems.

2. Morpho-physiological and Biochemical analysis

Various morpho-physiological parameters were selected (Table-01) and observations were made by visual examination for compilation of the results.

3. Morpho-Physiological Characteristics of leaf

Various morpho-physiological parameters selected for study of *Litsea salicifolia* leaf are summarized as below:

Table-01: Morpho-physiological parameters of *Litsea salicifolia* leaf:

S. NO.	PARAMETER	OBERVATION
1.	Sprouting Time	March – April
2.	Leaf Shape	Long elliptic to lanceolate
3.	Leaf Apex	Acuminate
4.	Leaf Base	Acute
5.	Leaf Margin	Entire
6.	Leaf Pubescence	Young leaves/glaucous undersides: yellow-brown puberulent (when young) abaxially; adaxial glabrous
7.	Leaf Color	Upper surface glabrous, likely green; underside glaucous (bluish-green) when young, older become glabrous.
8.	Leaf Texture	Leathery to semi-coriaceous
9.	Leaf length(cm)	9-19 cm
10.	Leaf Width (cm)	3-5.5 cm
11.	Fresh Leaf Weight (100 leaves) (g)	80g
12.	Dr Leaf Weight (100 leaves) (g)	26g
13.	Moisture (%)	70.1%
14.	Moisture Retention Capacity (MRC%)	67.5%
15.	Internodal Distance (cm)	4.6cm
16.	Leaves/meter twig (nos.)	21 nos.
17.	Inflorescence	Umbels, axillary, in clusters of 2-6; male umbels 4-6-flowered.
18.	Period of Inflorescence	Flowering Apr-May
19.	Onset of Fruit/ fruiting season	Fruiting June-September
20.	Type of Fruit	Fruit oblong (drupaceous / berry-like)
21.	Color of Fruit	Initially green and gradually turns Black
22.	Size of Fruit	10-11 × 5-6 mm

Plate-01: Morphology of Digloti (*Litsea salicifolia)*.

4. Conclusion

Litsea salicifolia exhibits favourable phenology, stable morphology, and strong rearing performance, making it a promising supplementary host for *Antheraea assamensis*. High larval survival and comparable cocoon and filament yields highlight its potential to diversify host plant resources in muga sericulture. Further biochemical and field evaluations across seasons are recommended to optimize its large-scale utilization under varying climatic conditions.

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PLASMA TECHNOLOGY- A NEW DIRECTION IN POST-HARVEST SECTOR

Introduction

Consuming fresh vegetables and fruits is perfect for our body since they are full of nutrients. Today, consumers prefer food that not only comes in high quality and is safe, but also lasts longer. But these food items are prone to easily acquiring bad germs while they are harvested and transported. We have traditionally employed processes such as chlorine washing or heat to clean and preserve food. The issue is that heat can alter the flavor and texture, and chemicals aren't healthy for us or the planet. For these reasons, the food industry is seeking greener, safer alternatives. This has resulted in new technologies that have the capability of making food safe without applying heat. One of the most promising of these is referred to as **"cold plasma".**

Plasma is a unique type of energized gas containing strong, natural cleaning agents that can destroy spoilage germs and inactivate enzymes that cause food to spoil without having to warm it up. It is an extra-energetic gas in which some particles are charged electrically

It may be created in two general ways:

1. Low-Pressure Cold Plasma (LPCP): Created in a sealed vacuum-like condition.
2. Atmospheric Pressure Cold Plasma (APCP): Developed under normal air pressure which is more suitable for industrial applications.

Some of the most common techniques are Dielectric Barrier Discharge (DBD) where two electrodes are separated by an insulator and Plasma Jets which discharge a stream of plasma onto the surface of the food. These techniques are widely used due to their versatility and ease of manipulation.

The Mechanism of Plasma Technology

1. Attack on Microbes: The reactive particles and UV light from the plasma hit microbial cells causing physical damage to their cell walls and membranes. This leads to leaks and eventually cell death. They can also harm the microbe's DNA, preventing it from reproducing.

2. Effects on Food Quality: It can stop enzymes like polyphenoloxidase (PPO) and peroxidase (POD) which cause browning in cut fruits such as apples and potatoes. The reactive species can also change the food's surface slightly which in some cases can speed up drying processes such as for mushrooms.

Application in Postharvest Management

The use of Cold Plasma in the postharvest management is of highly importance such as**:**

1. **Powerful Microbial Decontamination**: It effectively eliminates harmful food borne pathogens such as *E. coli*, *Salmonella*, and *Listeria* on the surface of fruits and vegetables. It also combats fungi and molds that lead to rot. Research has shown that it can reduce *Salmonella* on tomatoes by over 4 logs and eliminate *E. coli* on lettuce.

2. **Extended Shelf Life**: By destroying spoilage microbes and slowing the ripening process, it helps produce last longer. It has been shown to reduce weight loss, maintain firmness, and preserve color in various fruits. Tomatoes treated with this technique remained fresh for 10-15 days longer than untreated ones.

3. **Increase of Bioactive Compounds**: The mild stress from this can trigger a protective response in fruits and vegetables, leading to more beneficial antioxidants like phenolics, flavonoids, and anthocyanins. Treatments have been shown to raise phenolic content in bananas and anthocyanin levels in blueberries.

4. **Reduction of Pesticide Residues**: It can break down harmful pesticide residues on the surface of produce enhancing food safety. Reductions of up to 79% in pesticides like chlorpyrifos on lettuce have been reported.

Applications for Specific horticultural crops

1. **Apples**: This is effective for cleaning surfaces and apple juice. It can also increase polyphenol content.

2. **Berries (Strawberries, Blueberries)**: This works well for reducing mold and bacteria on these perishable fruits. It also improves their already high levels of antioxidants and vitamins.

3. **Leafy Greens (Lettuce, Spinach)**: This is an important tool for lowering pathogen levels on greens, which often link to foodborne illness outbreaks. Soaking greens in "Plasma-Activated Water" is also an effective method.

4. **Tomatoes**: This treatment not only cleans tomatoes but also slows ripening, keeps vitamin C content and can even be used on seeds to boost their germination and growth.

Constrains of cold plasma technology

1. **Scaling Up**: It is difficult to move from small lab equipment to large, cost-effective industrial systems.

2. **No Universal Setting**: Each fruit and vegetable needs specific treatment parameters, such as time, gas, and power. This makes standardization challenging.

3. **Surface-Level Action**: The plasma only reaches the surface and cannot go deep into the flesh, so it doesn't affect internal microbes or spoilage.

4. **Quality Risks**: It can sometimes harm delicate foods, leading to discoloration, off-flavors, or a soft texture.

5. **Regulatory Hurdles**: The absence of universal regulations and safety standards slows commercial adoption.

6. **High Cost**: The significant initial investment for equipment is a barrier for many companies

Conclusion

It is an effective, flexible, anti-microbial process with potential applications to a wide variety of foods. This technology has gained increased popularity due to its potential contribution to non-thermal food processing. This treatment offers various opportunities in processing industry such as surface decontamination, modification of surface properties, waste water treatment etc. This technology opens new perspective for lowering the microbial count on food surfaces.

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ARTICLE ID: 08

White Siris (*Albizia procera*): futuristic commercial tree for Agroforestry in India

Abstract: *Albizia procera* is commonly known as white siris and has emerged as a promising species in agroforestry systems due to its rapid growth. multifarious use and have potential of adaptability to a wide range of climate. This article aims to address the highlights of its botanical characteristics, potentials in agroforestry systems, emphasizing its role in reforestation, agroforestry, and sustainable forestry practices. The paper synthesizes existing research to offer insights into the potential and challenges of integrating Albizia procera into sustainable agroforestry practices in India.

Keywords: Albizia procera, Multifarious uses, suitability, Agroforestry systems, Potential

1. Introduction

Agroforestry is emerging as a promising land-use system in the Indian subcontinent which incorporates trees, crops, and often livestock for enhancement of productivity, livelihood, and ecological balance. Among the multipurpose tree species, *Albizia procera* is most outstanding due to its characteristics of fast growth, soil-enriching capacity, and wide adaptability. It is locally known as *Safed Siris* or *Safed Babool*, this deciduous leguminous woody perennial has immense potential for becoming a good choice for a futuristic commercial species for Indian agroforestry landscapes (**Tiwari and Dhuria, 2018**).

2. Botanical and Ecological Features: *Albizia procera* is taxonomically placed in the family *Fabaceae* and is native to the Indian subcontinent and Southeast Asia. It is generally moderate to large-sized tree, reaching 20–30 meters in height with a spreading crown and pale bark. It is a nitrogen-fixing species, improves soil fertility and supports intercropping systems. It has a deep root system and drought tolerance potential which makes it suitable for growing to semi-arid and sub-tropical regions **Sivakrishnan & Swamivelmanickam, 2019.**

3. Agroforestry Potential: White siris is performing well in dry, semi arid regions including bundelkhand and central India due to its multifarious uses and wider applicability in different agroforestry systems.

a. Fast Growth and Nitrogen Fixation: White Siris is an excellent nitrogen fixer and it fixes nitrogen symbiotically and enriches soil fertility for companion crops. Review of literature suggests that it can fix up to 200 kg N/ha/ annually and reduce applicability of synthetic fertilizers.

b. Multipurpose Use

- **Timber and Wood:** The wood of this species is found to be moderately heavy, durable, and appropriate for making furniture, agricultural tools and agricultural tools **Das *et al.*2023.**
- **Fuelwood and Charcoal**: White siris is an excellent source of firewood and charcoal due to its high calorific value wood around 4800–5000 kcal/kg. **Das *et al.*2023.**
- **Fodder:** Tender leaves and pods serve the purpose of excellent fodder for cattle and goats especially during lean seasons.
- **Soil Improvement**: The Leaf litter decomposition is widely used for the enrichment of organic matter and retention of moisture in soil.

c. Crop Compatibility

White Siris has a light canopy, allowing filtered sunlight to reach the ground. This makes it suitable for intercropping with cereals, pulses, and vegetables in the initial years. Crops such as wheat, mustard, black gram, green gram, sesame, and millets have shown compatibility in various agroforestry trials.

4. Role in Sustainable Land Use and Climate Resilience

White Siris is growing in a variety of soils from loamy to lateritic, rainfall zones of 750–1500 mm and tolerates seasonal drought, this property fits it to suit in semi-arid regions like Bundelkhand, Vidarbha, and parts of central India. Further its potential to be resistant to browsing and potential to coppice vigorously make it an excellent choice for agroforestry systems and wasteland rehabilitation. White Siris addresses challenges of soil degradation, water scarcity, and climate variability, especially in semi-arid zones through:

- **Carbon Sequestration**: White siris mature stands have potential to sequester 8–10 t C/ha, contributing to mitigation of climate change.
- **Land Rehabilitation**: Due to its potential to colonize at degraded, ravine, and it stabilizes soil and prevents erosion.
  - **Biodiversity Support**: It crown provides nesting habitats for birds and flowers attract pollinators.
- **Low Management Demand**: After the establishment species requires minimum inputs, and makes it best for small and marginal farmers.

5. Agroforestry Models and Research Outlook

In recent decades the research under ICAR and ICFRE are emphasis the incorporation of Albizia procera in boundary plantations, alley cropping, and agri-silvicultural systems especially for Semi arid regions.Albizia procera was enlisted in ICAR-Central Agroforestry Research Institute (CAFRI) published consortium of about 40 successfuly tested well-researched Prospects for wastelands greening and restoration with agroforestry systems suitable for wastelands and degraded lands (**Handa *et al.*, 2019**). Also, it is recommended for successful agroforestry systems for income enhancement and ecosystem services are documented at country level by ICAR-CAFRI.

Conclusion: White Siris is the one of promising species of the future for sustainability and commercial agroforestry in India. It has immense potential for providing economic returns accompanied with environmental benefits and makes it a promising species for climate-resilience systems of farming. In the nutshell due to diversified applicability and compatibility with Indian farming systems. It is the perfect choice for farmers, entrepreneurs, and industries visioning for green growth.

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BIOCONVERSION OF AGRO-WASTES INTO FUNCTIONAL FOOD INGREDIENTS: A BIOTECHNOLOGICAL PERSPECTIVE

Abstract
This article details the imperative and methodology for valorizing agro-industrial residues into high-value functional food ingredients via biotechnological processes. Uncontrolled waste disposal through burning, dumping, and landfilling creates severe environmental and health concerns, necessitating a shift toward a circular bioeconomy. Bioconversion strategies, including cost-effective Solid-State Fermentation (SSF) and targeted enzymatic hydrolysis, transform complex lignocellulosic feedstock into functional ingredients. Key products include prebiotic oligosaccharides, highly active antioxidant polyphenols, and novel proteins (Single-Cell Protein and insect biomass), all of which provide documented health benefits, such as enhanced antioxidant activity and improved digestive and metabolic health. However, industrial commercialization faces major hurdles, specifically biotechnological limitations like lignin inhibition of enzymes, and lengthy regulatory approval processes, including the US FDA's Generally Recognized As Safe (GRAS) notification and the EU's European Food Safety Authority (EFSA) Novel Food review. Overcoming these scale-up and regulatory obstacles is crucial for realizing the substantial economic potential (projected $50 billion market by 2025) of this sustainable transformation within the global food system.
Keywords: Agro-industrial residues, Biotechnological processes, Functional food ingredients, Solid-State Fermentation (SSF), Regulatory approval

1. Introduction: The Mandate for Agro-Waste Valorization

1.1 Global Imperative and the Circular Bioeconomy Model

The agricultural and food processing sectors discard approximately one-third of the world's fresh harvest, creating a massive, underutilized waste stream. Conventional disposal methods—burning, casual dumping, or landfilling—are a major source of greenhouse gas emissions and contribute to environmental contamination and disease spread. The solution lies in valorization: converting these low-value residues into high-value bioproducts that align with the principles of the circular economy. Functional food ingredients are compounds that offer specific health benefits beyond basic nutrition, such as bioactive peptides, organic acids, phenolic compounds, and dietary fibers. This strategy shifts the linear "take-make-dispose" paradigm to one of resource integration, promoting sustainability and applying to sectors across the "agri-food-pharma" nexus.

1.2 Economic Imperatives and Market Projections

Valorization is driven by compelling financial factors; converting residual biomass into functional ingredients can increase agricultural income by a measurable 15-40% while simultaneously offsetting operational disposal costs. The rapid global demand for natural and sustainable food ingredients is fueling explosive market growth. The global market for these agro-waste derived products is projected to reach $50 billion by 2025, offering strong economic viability.

2. Biotechnological Platforms for Waste Bioconversion

Effective valorization of lignocellulosic biomass (LCB) requires specialized biotechnological platforms, often preceded by essential pretreatment steps.

2.1 Pretreatment and Lignin Inhibition

Raw LCB is challenging to process because lignin physically shields key compounds like cellulose, inhibiting microbial and enzymatic access. Therefore, initial pretreatment steps are necessary to disrupt the substrate structure, reduce lignin content, and improve the accessibility of carbohydrates for biocatalysts. Studies frequently utilize physicochemical pretreatment, such as dispersing potato peel residues in 1% (v/v) H_2SO_4 or 1% (w/v) NaOH, followed by high-temperature incubation (e.g., 121℃ for 30 minutes).

2.2 Microbial Fermentation Techniques (SSF vs. SmF)

Microbial fermentation is essential for synthesizing functional molecules and converting complex structures into bioavailable forms.

Solid-State Fermentation (SSF), where microorganisms grow on a damp, solid substrate in the absence of free water, is the most strategic platform for agro-waste. SSF offers strategic cost advantages: it requires lower water consumption, uses less energy, and avoids the capital-intensive stainless-steel bioreactors required by Submerged Fermentation (SmF). Furthermore, SSF often yields higher product concentrations and is particularly suitable for filamentous organisms, such as *Rhizopus oligosporus* and *Bacillus subtilis*, as the solid matrix resembles their natural habitat. While SmF provides superior environmental control, SSF's high cost-effectiveness and low operational expenditure make it the most economically viable approach for large-volume, low-cost agro-waste processing.

2.3 Enzymatic Hydrolysis and Advanced Protein Routes

Enzymatic saccharification is critical for breaking down complex polysaccharides into value-added intermediates, primarily prebiotic oligosaccharides, including cellooligosaccharides (COS), pectooligosaccharides (POS), and xylooligosaccharides (XOS). This process is highly controlled and occurs under mild aqueous conditions, offering an advantage over harsh acid treatments. However, a significant technical limitation is that residual lignin physically inhibits enzyme accessibility, which directly lowers the yield of saccharides, necessitating optimized pretreatment prior to hydrolysis.

3. Functional Ingredients: Recovery and Characterization

The application of bioconversion techniques yields a diverse array of functional compounds:

3.1 Bioactive Compounds: Phenolics and Antioxidants

Agri-food by-products are rich sources of bioactive compounds, notably polyphenols, carotenoids, and dietary fibers. Extracts from fruit pomace, a rich source of polyphenols, have demonstrated antioxidant activity in *in vitro* studies that is 2 to 10 fold higher than common synthetic antioxidants such as BHT and BHA. These compounds are crucial for preventing oxidative stress-related diseases, including cancer and cardiovascular disease. Fermentation is effective at releasing bound polyphenols; for example, bioconversion of cereal bran yields significant amounts of phenolic acids (like ferulic acid) contributing to total phenolic content reaching up to 11, 100 GAE.

3.2 Dietary Fibers and Prebiotics

Agro-waste derived ingredients are instrumental in enhancing the fiber profile of foods. Incorporating fruit pomace at 5-15% levels in bakery applications can increase the total dietary fiber content by 50% to 200%. Prebiotic oligosaccharides (XOS, POS, COS), obtained through enzymatic hydrolysis, selectively stimulate the growth of beneficial gut microflora. These compounds can increase the populations of beneficial bacteria by 100 to 1000 fold while suppressing pathogenic microorganisms. This action modulates beneficial gut bacteria, promoting the production of short-chain fatty acids (SCFAs) and improving gut microbiome balance, which is linked to enhanced immune function.

Table: Functional Food Ingredients Derived via Agro-Waste Bioconversion

Agro-Waste Source	Bioconversion Method	Key Value-Added Ingredient	Nutritional Function
Fruit Pomace (Apple, Grape)	SSF, Enzymatic Hydrolysis	Pectooligosaccharides (POS), Polyphenols, Dietary Fiber	Prebiotic activity, Antioxidant, Cholesterol reduction
Cereal Bran (Wheat, Rye)	SSF, Chemical/Enzymatic	Dietary Fiber, Phenolic Acids (Ferulic acid), Alkylresorcinols	Digestive health, Antioxidant, Metabolic regulation
Lignocellulosic Biomass	Microbial SCP Fermentation (Yeast/Bacteria)	Single-Cell Protein (SCP: 40–80% Protein)	Complete essential amino acids, Protein supplementation
Vegetable/Food Residues	Insect Bioconversion (BSF Larvae)	Protein and Lipid Biomass (30–57% Protein)	High-value protein source, Superior waste reduction

3.3 Novel Protein Sources

Innovative bioconversion platforms efficiently transform waste into high-quality protein and lipid sources. Single-Cell Proteins (SCP), microbial biomass grown on agricultural wastes (e.g., rice straw, starchy residue), typically contain an impressive protein content ranging from 40% to 80% of the dry cell weight, offering a balanced profile of essential amino acids. In Insect Bioconversion, insects like the Black Soldier Fly (BSF) larvae valorize low-value organic waste (e.g., vegetable residues) into high-quality biomass. Defatted BSF meals can reach up to 57% protein content, depending on the feedstock, providing a high-value protein and lipid source alongside significant waste reduction.

4. Applications and Demonstrated Health Benefits

The recovered compounds are integrated into functional foods to address chronic health issues.

The primary application involves nutritional enhancement; for instance, incorporating fruit pomace into bread formulations increases phenolic content by 3-5 fold. Advanced technology, such as nanocapsules, is utilized to micro- or nano-encapsulate bioactive molecules to enhance their stability, efficacy, and controlled release in food applications.

The prebiotic and fiber components deliver significant digestive and metabolic benefits. Soluble fibers can reduce cholesterol absorption by 10-15%. Regarding metabolic health, phenolic compounds demonstrate anti-diabetic potential by inhibiting carbohydrate-digesting enzymes, resulting in a measurable 15-30% reduction in postprandial glucose spikes. Furthermore, bioactive protein peptides derived through bioconversion exhibit Angiotensin-Converting Enzyme (ACE)-inhibitory activity, which has been shown to reduce systolic blood pressure by 5-15 mm Hg in clinical settings, underscoring their cardiovascular benefits.

5. Conclusion

Bioconversion of agro-wastes into functional food ingredients is a crucial strategy for achieving sustainability, enhancing public health, and creating economic value. The use of biotechnological processes like SSF and enzymatic hydrolysis efficiently yields high-value prebiotics, antioxidants, and protein biomass. To fully capitalize on the projected market growth, the industry must invest in refining green pretreatment methods to overcome lignin inhibition and optimize robust, continuous biorefining and advanced extraction techniques. Successful market entry ultimately depends on strategic planning to navigate the scientifically demanding and lengthy regulatory processes required by the FDA GRAS and EFSA Novel Food protocols. By resolving these technical and regulatory challenges, agro-waste derived functional ingredients are positioned to become foundational components of a truly circular and sustainable global food system.

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From Farm to Fork: Safe Value Addition Practices in Milk, Meat, and Egg Products to safeguard the Public Health

Introduction: The Nutritional Powerhouse and the Hidden Risk

Milk, meat, and eggs are not just foods; these are fundamental pillars of human nutrition. Across India and much of the developing world, these animal-origin foods provide essential amino acids, vitamins, and minerals that are critical for growth, brain development, and immune strength. As dietary patterns shift and incomes rise, the demand for animal-source foods continues to soar. India, is now the world's largest milk producer and among the top consumers of poultry and fish products (FAO, 2022).

However, with this growing demand comes a pressing challenge: how to ensure that the food reaching consumers is safe, hygienic, and nutritious. The journey of these foods from animals on farms to neatly packaged items on store shelves is a long and complex process. At every step, there are opportunities for contamination if good hygiene and temperature control are neglected. Unsafe animal products are the leading causes of foodborne illnesses, which, according to the WHO, 2023, affect over 600 million people globally each year.

This is where the concept of "From Farm to Fork" becomes vital. It advocates for an integrated approach to ensure food safety and traceability across the entire value chain. This include adaptation of hygienic handling, maintaining a robust cold chain, and ensuring transparency and traceability all of which directly safeguard public health and create opportunities for value addition and entrepreneurship.

The Promise of Value Addition in Animal-Origin Foods

Value addition refers to any process that increases the economic worth and consumer appeal of a product. For milk, this could mean producing flavoured milk, cheese, yogurt, paneer, or milk-based sweets. In the meat sector, value addition includes items like sausages, nuggets, ready-to-cook marinated products, or shelf-stable meat curries. Eggs too can be turned into liquid eggs, powdered eggs, or high-protein snack products.

Beyond improving taste and shelf life, safe value addition directly contributes to food security, employment, and rural income generation. Small-scale entrepreneurs, self-help groups, and women's cooperatives can all benefit from developing hygienic, locally-branded value-added products.

But value addition must not come at the cost of safety. In fact, safety is its foundation. When done right, it enhances both public health and consumer confidence, also create a win–win situation for producers and the public alike.

Hygienic Handling: The First Line of Public Health Defence

The journey to safe food begins long before it reaches a processing plant, it starts at the farm level. The health and hygiene of the animals themselves are crucial. Animals raised in unhygienic environments, exposed to contaminated water, or fed poor-quality feed are more prone to infections, some of which can transmit to humans (zoonoses).

At the Farm Level

- **Healthy livestock:** Regular veterinary check-ups, vaccination, and parasite control are essential. Sick animals should never enter the food chain.
- **Clean housing:** Animal sheds should have proper drainage, ventilation, and regular disinfection schedules.
- **Hygienic milking and egg collection:** Milking should be done with sanitized equipment and clean hands. Eggs should be collected promptly, stored at the correct temperature, and never washed in dirty water.

During Slaughter and Processing

In abattoirs and processing facilities, hygiene is even more critical. Cross-contamination from surfaces, tools, or workers can easily spread bacteria such as *Salmonella*, *Listeria monocytogenes*, and *E. coli* etc. To mitigate this:

- Carcasses must be processed in sanitary environments.
- Workers should use personal protective equipment (PPE) like gloves, masks, and aprons.
- Equipment must be regularly cleaned with food-grade disinfectants.
- There should be segregation of clean and dirty zones to prevent recontamination.

Good Hygienic Practices (GHP) and Good Manufacturing Practices (GMP)

Training workers in GHP and GMP is a cornerstone of safe processing. These ensure cleanliness, prevent physical and chemical contamination, and set the stage for more advanced systems such as Hazard Analysis and Critical Control Points (HACCP).

For example, the Food Safety and Standards Authority of India (FSSAI) has developed specific training modules for dairy and meat handlers under its *Food Safety Training and Certification (FoSTaC)* program, for promoting scientific food safety culture among entrepreneurs and small-scale processors (FSSAI, 2023).

Cold Chain Management: Keeping Safety and Quality Intact

Animal-origin foods are among the most **temperature-sensitive commodities**. The microorganisms that cause spoilage or disease multiply rapidly at warm temperatures. Maintaining a cold chain from farm collection to retail display is therefore not optional; it is the backbone of food safety.

Every animal-origin food has its own “safe temperature window.”

- **Milk:** Below 4°C from collection to processing.
- **Meat and poultry:** 0–4°C for chilled meat, and -18°C for frozen storage.
- **Eggs:** 8–15°C with consistent humidity to prevent shell cracks and microbial growth.

When the temperature fluctuates, microorganisms thrive, leading to spoilage, toxin formation, and foodborne illness. A lapse of even a few hours in the cold chain can make the product unsafe.

Challenges in India and Developing Economies

Despite rapid growth in the dairy and poultry sectors, cold chain infrastructure remains a major bottleneck. In many regions, unchilled milk or meat is transported in open containers, often over long distances. This not only reduces product quality but also increases health risks.

To overcome these issues, several innovations are emerging:

- **Solar-powered milk chillers** for remote dairy farms.
- **Insulated mobile vans** for meat and egg transport.
- **Community cold storage units** for small producers and cooperatives. Such technologies can dramatically reduce post-harvest losses which was estimated over 15–20% for perishable animal products in India by NITI Aayog, 2022.

Entrepreneurial Opportunity in Cold Chain Services

Cold chain infrastructure is not just a safety requirement. It is a business opportunity. Entrepreneurs who invest in small-scale refrigerated transport, rural milk chilling units, or smart temperature-monitoring systems can significantly strengthen safe food value chains while creating sustainable income opportunities.

Traceability: The Future of Safe and Transparent Food Systems

Consumers today are increasingly aware and concerned about where their food comes from. Food traceability: the ability to track the history, application, or location of a food item, is therefore emerging as a public health and market necessity.

What Is Traceability and Why Does It Matter?

Traceability enables the tracking of a product’s journey from the source to the final consumer. It includes details such as the farm of origin, processing date, batch number, and transportation history. In the event of contamination or a foodborne outbreak, traceability allows for quick recalls and investigation, minimizing risk to consumers.

In value-added products like cheese, sausages, or pasteurized eggs, traceability also builds consumer trust. A simple QR code on packaging can tell a customer where the milk was collected, when it was pasteurized, and even the name of the cooperative that produced it.

Digital Tools for Modern Traceability

- **Blockchain technology:** Creates tamper-proof, decentralized records of the food chain.
- **RFID tags and barcodes:** Enable real-time tracking of batches during transport and storage.
- **Mobile apps:** Help small farmers register their products and build transparent supply chains.

Countries like Denmark and New Zealand have already implemented national traceability systems for dairy and meat, ensuring quick responses to safety incidents. India is also moving forward through FSSAI’s *Food Safety Connect* platform and initiatives like the *Clean Street Food Hub* certification program, which emphasize transparency and hygiene (FSSAI, 2023).

Foodborne Zoonoses: We Must Reduce the Health Burden

Unsafe animal-origin foods contribute significantly to the global burden of foodborne disease. Pathogens like *Salmonella spp.*, *Campylobacter*, *Brucella*, and *Listeria* are commonly transmitted through contaminated meat, milk, or eggs. According to WHO (2023), more than 420,000 people die annually due to foodborne illnesses many of which are preventable with basic hygiene and temperature control.

Moreover, poor processing and misuse of antimicrobials in livestock can promote antimicrobial resistance (AMR), posing a global health threat. The "One Health" approach, integrating animal, human, and environmental health perspectives, calls for safer animal production and processing systems to prevent spillover of resistant pathogens into the food chain.

Public Health Implications and Socioeconomic Dimensions

Improving hygiene and traceability in animal product value chains benefits not only consumers but also the broader economy. Safe products reduce disease burden, improve workforce productivity, and open export markets. For instance, the European Union mandates strict traceability and hygiene standards for all imported animal-origin foods. Compliance with such standards can unlock new export opportunities for Indian entrepreneurs.

Furthermore, promoting women and youth entrepreneurship in hygienic, small-scale processing units can enhance rural livelihoods. Training programs under schemes like *National Livestock Mission* and *Startup India* already support dairy and poultry-based enterprises that integrate food safety and public health goals.

Role of Institutions and Policies

Ensuring safety "from farm to fork" requires coordinated efforts from multiple stakeholders: farmers, processors, regulators, and consumers.

Government Initiatives

- **FSSAI's "Eat Right India" movement** focuses on ensuring safe, healthy, and sustainable diets through better hygiene, fortification, and food testing.
- **National Dairy Development Board (NDDB)** has implemented *Clean Milk Production* programs that promote on-farm hygiene and rapid chilling at the village level.
- **Department of Animal Husbandry and Dairying (DAHD)** promotes modernization of abattoirs and meat processing plants with scientific waste disposal and cold chain support.

International Guidelines

- **Codex Alimentarius Commission (2021)** provides global standards for hygienic production of milk, meat, and eggs.
- **FAO's Good Hygiene Practices for Dairy Processors (2020)** and **OIE's Terrestrial Animal Health Code** offer guidance for countries to align food safety systems with international norms.

Such frameworks not only protect health but also boost global trade confidence in animal-origin foods.

Sustainable and Safe Value Addition: The Way Forward

The next phase of food entrepreneurship must blend **safety, sustainability, and innovation**. The use of renewable energy for cold storage, biodegradable packaging, and smart sensors for temperature and contamination monitoring are transforming how food is processed and delivered.

Consumers increasingly prefer products labeled as "antibiotic-free," "pasteurized," or "traceable." Hence, investing in safety technologies is not merely a regulatory obligation but a strategic marketing advantage.

Moreover, educational campaigns on hygiene and responsible consumption can make consumers active participants in food safety. The "Eat Right Campus" and "Clean Street Food Hub" models in India are excellent examples of how awareness can improve both business and health outcomes.

Conclusion: Safe Value Addition as a Public Health Investment

Ensuring that milk, meat, and egg products are safe is not only about prevention of diseases. It is about building a healthier, more resilient society. The "Farm to Fork" approach underscores that food safety is a shared responsibility. When farmers adopt hygienic practices, processors maintain cold chains, and distributors ensure traceability, consumers receive not just food, but safe, nutritious, and trustworthy nourishment.

In the era of global trade and rapid urbanization, countries that prioritize food safety and traceability will lead both economically and socially. Entrepreneurs who invest in hygienic, innovative, and transparent value addition will not only gain profits but also contribute significantly to **public health protection** and **sustainable development**.

As the saying goes,

"Healthy food means healthy people and healthy people build a healthy nation."

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Unlocking the Potential of Carbon Credits: How Carbon Trading Empowers Farmers and Mitigates Climate Change

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1. ABSTRACT

Agriculture is emerging as one of the most effective arenas for addressing climate change. Through carbon credits, farmers can convert sustainable practices into measurable economic rewards. These credits represent verified reductions or removals of greenhouse gases, enabling a marketplace where climate-positive actions create tangible income (Cariappa et al., 2024). Practices such as conservation tillage, agroforestry, and biochar application enhance soil organic carbon and reduce emissions while maintaining productivity (Ravindranath et al., 2022). Digital monitoring, reporting, and verification (MRV) systems—using satellites, sensors, and blockchain—now make participation credible and transparent (Boumaiza et al., 2024).

However, smallholder farmers face challenges such as high transaction costs, limited technical knowledge, and weak market linkages (ICAR-CRIDA, 2025; Ghosh & Sharma, 2024). Government initiatives like India's Green Credit Programme and the Voluntary Carbon Market in Agriculture Protocol are designed to overcome these barriers. With policy support, inclusive governance, and digital innovation, carbon trading can integrate rural livelihoods into global climate solutions while promoting equity and resilience.

Keywords: agroforestry; regenerative farming; smallholder inclusion; digital MRV; carbon sequestration; climate-smart agriculture; policy frameworks

2. INTRODUCTION

Agriculture sits at the crossroads of climate change both a major emitter and a potential carbon sink. Globally, farming contributes nearly 30% of anthropogenic greenhouse-gas emissions through methane, nitrous oxide, and land-use change (Ritchie et al., 2022). Yet soils and vegetation can capture vast quantities of carbon, positioning agriculture as a cornerstone of mitigation. Carbon trading links this environmental function with financial incentives by rewarding emission reductions or sequestration (UNFCCC, 2015). Under such systems, one metric tonne of CO_2 equivalent reduced becomes a tradable unit—a carbon credit. In India, where more than half the population depends on farming, this mechanism offers a unique opportunity for sustainable development. By implementing conservation agriculture, residue retention, and efficient nutrient management, Indian farmers could collectively sequester millions of tonnes of carbon annually.

Nevertheless, barriers remain: high certification costs, limited awareness, and market volatility discourage participation. Addressing these issues requires policy alignment, institutional capacity, and farmer education (Ghosh & Sharma, 2024). This paper examines how carbon trading empowers farmers, enhances sustainability, and contributes to national climate targets, while highlighting pathways to make participation fair and accessible.

3. BACKGROUND

Carbon trading refers to a market-based mechanism allowing emission reductions or removals to be quantified, verified, and exchanged as credits. Each credit equals one tonne of CO_2 equivalent. Two main market types exist: compliance markets—mandated by law, such as the EU ETS—and voluntary markets, driven by corporate or individual commitments (World Bank, 2023). The voluntary segment has expanded rapidly, valued at more than USD 2 billion in 2023 and projected to reach USD 100 billion by 2030. India has over 50 registered agricultural projects covering 16.5 million hectares (Ghosh & Sharma, 2024). Farmers participating in these initiatives adopt low-till systems, crop diversification, or agroforestry, verified under standards like Verra's VCS or Gold Standard.

3.1 HISTORY OF CARBON CREDITS

The concept of carbon credits emerged as a response to the need for international cooperation in reducing GHG emissions and addressing climate change (**Kolk et al., 2008**). Here is a brief history of carbon credits:

1. **1997: Kyoto Protocol** - The Kyoto Protocol, an international treaty to combat climate change, introduced market-based mechanisms to reduce emissions. It established the Clean Development Mechanism (CDM) and Joint Implementation (JI) as mechanisms for generating carbon credits (Matsuo, 2003).
2. **Clean Development Mechanism (CDM)** - The CDM allowed developed countries to invest in emission reduction projects in developing countries and earn Certified Emission Reductions (CERs) for each ton of CO_2e reduced. CERs could be used by developed countries to meet their emission reduction targets (Carr & Rosembuj, 2008).
3. **Emission Trading Systems** - In the early 2000s, various emission trading systems were established, such as the European Union Emission Trading Scheme (EU ETS). These systems allocated emission allowances to industries, creating a market for trading carbon credits (Kolk et al., 2008).
4. **Voluntary Carbon Markets** - Alongside compliance markets, voluntary carbon markets emerged to facilitate carbon offsetting beyond regulatory requirements. These markets allow businesses and individuals to voluntarily purchase carbon credits to offset their emissions and demonstrate environmental responsibility (Matsuo, 2003).
5. **Carbon Standards and Certification** - Several standards and certification bodies were established to ensure the credibility and integrity of carbon credits. These include the Verified Carbon Standard (VCS), Gold Standard, American Carbon Registry (ACR), and Climate Action Reserve (CAR), among others (United Nations, 2015).

6. **Paris Agreement** - The Paris Agreement, adopted in 2015, encouraged market-based approaches to support emission reductions. The agreement recognizes the importance of carbon markets and calls for enhancing and coordinating international cooperation in this regard (United Nations, 2015).

Today, carbon credits play a significant role in both compliance and voluntary markets, enabling businesses, governments, and individuals to take climate action, achieve emission reduction targets, and support sustainable projects worldwide (AGRI Journal World, 2023).

3.2 TYPES AND ALLOCATION OF CARBON CREDITS IN AGRICULTURE

Carbon credits in agriculture reward farmers for adopting sustainable practices that reduce or capture greenhouse gas emissions. These include actions like using biofertilizers, practicing conservation tillage, adopting agroforestry, and improving soil carbon storage (ICAR-CRIDA, 2025; AGRI Journal World, 2023). Farmers can earn credits for these practices and trade them in carbon markets for additional income, contributing to both environmental and economic sustainability.

(I) Types of Agricultural Carbon Credits

- **Certified Emission Reductions (CERs):** Earned through approved carbon reduction projects in developing countries under the *Clean Development Mechanism (CDM)* of the Kyoto Protocol. Farmers adopting renewable energy or methane reduction projects can earn CERs (United Nations, 2015).
- **Verified Emission Reductions (VERs):** Generated in *voluntary carbon markets* for farm-based practices like agroforestry, organic farming, and composting. These are verified by independent bodies such as *Verra* or *Gold Standard* (Verra, n.d.; Gold Standard, n.d.).
- **Removal Units (RMUs):** Awarded for activities like reforestation, biochar use, and soil carbon enhancement that physically remove CO_2 from the atmosphere **(Carr & Rosembuj, 2008).**
- **Blue Carbon Credits:** Relevant for farmers involved in mangrove, wetland, or coastal agriculture, recognizing carbon sequestration in aquatic ecosystems (AGRI Journal World, 2023).

(II) Allocation and Benefits to Farmers

Carbon credits are allocated based on the verified amount of carbon reduced or removed through farm practices. The process includes measurement, reporting, and verification (MRV) using satellite or AI-based tools (Spacenus, 2025). Once verified, credits are sold on compliance or voluntary markets, allowing farmers to:

- **Earn extra income** by selling credits to companies seeking carbon offsets.
- **Improve soil health** through sustainable practices that increase carbon storage.
- **Reduce input costs** by promoting organic fertilizers and efficient irrigation.
- **Enhance climate resilience**, making farms more resistant to droughts and floods (**EOSDA, 2025; ICAR-CRIDA, 2025**).

4. REVIEW OF LITERATURE

Research over the last decade emphasizes agriculture's central role in carbon markets shows that conservation tillage, agroforestry, cover cropping, and residue management both sequester carbon and boost productivity (Cariappa et al., 2024; Ravindranath et al., 2022). Integrating smallholders through digital platforms and FPOs improves inclusion and transparency (ICAR-CRIDA, 2025). Yet challenges persist especially high transaction costs and uneven benefit sharing (CGIAR, 2023). Successful programs couple community aggregation, digital MRV and policy support to ensure equitable outcomes (Ghosh & Sharma, 2024).

4.1 HOW CARBON CREDITS WORK IN AGRICULTURE

Generating carbon credits starts with simple but impactful changes: planting cover crops, reducing chemical fertilizers, or introducing precision irrigation. Each of these actions, when properly measured and verified, can be translated into credits sold to companies needing to offset their own emissions (Drishti IAS, 2024). Today, digital monitoring and AI-driven analytics have made these processes more accurate and affordable, helping even small farms participate (Spacenus, 2025).

4.1.1 Benefits for Farmers

- *New Income Stream:* Participating in carbon credit markets gives farmers reliable access to additional earnings, supplementing income from their main crops. This extra revenue can help stabilize household finances and give families more flexibility in their operations (EOSDA, 2025).

- *Enhanced Climate Resilience:* Farm practices that store more carbon tend to make land more productive in the face of challenges like drought or floods. Robust soils retain water better and support healthier crops, reducing reliance on expensive inputs and safeguarding yields (Farmonaut, 2025).

- *Economic Stability:* By gaining money from multiple sources, farmers reduce their overall risks. Carbon credits reward long-term thinking, making it easier for producers to invest in better tools, seeds, or training—improvements that benefit whole communities over time (ICAR-CRIDA, 2025; EOSDA, 2025).

- *Economic Opportunities:* Carbon markets add a new revenue stream beyond crops. Demand for agricultural credits is expected to grow sharply as firms pursue net-zero targets (World Bank, 2023). Blockchain-based registries lower transaction costs and open global participation (Boumaiza et al., 2024). Cooperative aggregation further increases rural bargaining power.
- *Social Impact on Farmers:* Participating communities report better collaboration, information sharing, and access to climate finance (CGIAR, 2023). However, smallholders, women, and marginalized groups remain under-represented (Ghosh & Sharma, 2024). Inclusive design, equitable contracts, and gender-sensitive training are critical to prevent inequity.

4.1.2 Challenges and Solutions

- *Smallholder Participation:* Many small and marginal farmers lack awareness of carbon markets, technical know-how, or upfront funds to get started. Farmer aggregation through cooperatives, farmer-producer organizations, and support from NGOs or government programs is essential. Government frameworks can help lower entry barriers and make the system more inclusive, especially for underserved rural populations (ICAR-CRIDA, 2025; Farmonaut, 2025).

- *Monitoring, Reporting, and Verification (MRV):* It is costly and technically difficult to count every ton of carbon stored or saved by new farm practices. However, advances like drone imagery, satellite monitoring, and AI-powered apps now enable farms to keep accurate records and verify processes much more efficiently. This digitalization builds public trust and delivers quick, fair payments to producers (Spacenus, 2025; EOSDA, 2025).
- *Market Complexity:* Carbon markets are evolving, and transparency is crucial for success. Without clear contracts and equitable benefit-sharing models, small farmers may be underpaid or excluded. Initiatives that set standards for fair contracts and provide support for understanding market terms protect farmer interests. Capacity-building seminars and easy-to-understand training materials are also empowering producers to negotiate more confidently and make informed decisions (Farmonaut, 2025; EOSDA, 2025).

4.1.3 How Farmers Earn Through Carbon Credits

Farmers adopt eligible practices such as zero tillage or residue retention and baseline data are collected. Verified emission reductions are certified by standards like **Verra** or **Gold Standard** (Verra, 2023). Credits are aggregated and sold to corporate buyers through intermediaries or digital exchanges. Typically, 60–80 % of revenue reaches farmers after verification costs (Cariappa et al., 2024).

4.2 CARBON CREDITS IN CLIMATE MITIGATION

Carbon farming helps restore the balance of greenhouse gases by increasing the carbon stored in soils and plants, and by reducing harmful emissions from practices like residue burning or over-fertilization. These changes don't just help the planet-they also future-proof food systems, keeping farms productive in unpredictable environments (Welthungerhilfe, 2023; ICAR-CRIDA, 2025).

With support from international registries (like Verra or Gold Standard) and new national policies, more projects now recognize farmers as key climate solution providers. Still, ensuring fair access and reliable monitoring on a large scale is a challenge that requires innovation, transparency, and cooperation across many sectors (Farmonaut, 2025).

5. ROLE AND OPPORTUNITIES IN CLIMATE CHANGE AND MITIGATION BY INDIAN AGRICULTURE

India, a rapidly developing agrarian economy, stands at the crossroads of food security and climate responsibility. With developing countries expected to surpass the greenhouse gas (GHG) emissions of developed nations by 2050 (Chandler et al., 2002), India's agricultural transformation is key to global mitigation efforts. The country's population is projected to grow by 1.12% annually between 2022 and 2031, surpassing the global rate of 0.96% (United Nations, 2022). Rising incomes are likely to increase demand for high-footprint foods such as dairy and meat (OECD, 2023a), potentially doubling India's per capita CO_2 emissions from

1.53 tCO_2e in 2013 to 2.98 tCO_2e by 2030 (Narain, 2021; World Bank, 2022c). The agriculture sector contributes around 14% of India's GDP and 17% of its national GHG emissions (Chand & Singh, 2023; MoSPI, 2023). A conceptual pie chart (Figure 1) illustrates emission distribution within agriculture—major sources include enteric fermentation, rice cultivation, agricultural soils, and a residual "Others" category encompassing manure and crop residue burning (FAO, 2020). The use of inefficient technology and fossil fuels throughout food processing, transport, and storage further exacerbates emissions (Mrowczynska-Kaminska et al., 2021).

To mitigate emissions, the adoption of Sustainable Agricultural Practices (SAPs) can substantially reduce India's carbon output—from 11.8 $GtCO_2e$ in 2019 to 1.9 $GtCO_2e$ by 2070 (Bhattacharya, 2019; Gupta et al., 2022). These practices also improve soil health, resource-use efficiency, and farmers' income through carbon credits.

Table 1. Climate-Smart Agricultural Technologies and GHG Mitigation Potential

Technology	Application and Potential
Feed additives & manure management	Balanced cattle feed and manure management can reduce CH_4 and N_2O emissions by up to 85% and 41% respectively (Vijayakumar et al., 2022; Sapkota et al., 2019). Family-size biogas units may offset **0.5 Gt CO_2 e** annually (Raipurkar, 2023).
Solar energy	Solar pumps replace diesel units, reducing **5 t CO_2e yr^{-1}** each (Agrawal & Jain, 2018). Solar drying prevents 30–50% of post-harvest losses (Kapri, 2021).
Drip/Micro irrigation	Lowers CH_4 emissions by 21%, enhances yield by 20–50%, and saves up to 60% of water (Zhang et al., 2020; Ranjan & Sow, 2020).
Laser land leveling (LLL)	Saves 10–14% irrigation water and cuts 754 kWh electricity per hectare annually; mitigates **1.28–3 t CO_2 e ha^{-1} yr^{-1}** (Jat et al., 2009; Aryal et al., 2015; Sapkota et al., 2019).
Direct seeded rice (DSR)	Improves water efficiency by 50% and reduces GWP by up to 59% in Punjab (Ishfaq et al., 2020; Pathak et al., 2014).
Intercropping & biochar	Intercropping reduces N fertilizer by 15%, while biochar lowers CH_4 emissions by 79% and increases crop yield by 10% (Harrison et al., 2022; Chamkhi et al., 2022; Nair & Mukherjee, 2022).
Zero tillage (ZT)	Reduces fuel use by 3.9 gallons per acre and lowers GHG emissions by 8–31% compared with conventional tillage (Li et al., 2023; Jain et al., 2023).

Sapkota et al. (2019) estimate that India's agriculture could emit 515 $MtCO_2e$ annually by 2030, of which SAPs can offset 85.5 $MtCO_2e$ per year. ZT, efficient fertilizer use, and rice water management together could sequester 43 $MtCO_2e$ yr^{-1}. At a carbon price of $10 per credit, farmers practicing ZT could earn INR 250–900 per hectare annually, while LLL could generate INR 600–1500.

Despite these benefits, small farmers face barriers such as high initial costs, low awareness, and insecure land tenure (Ruzzante et al., 2021). Policies like the Green Credit Program, PM-PRANAM, and MISHTI, as well as India's developing Voluntary Carbon Market (VCM) framework, aim to encourage sustainable adoption (MoAFW, 2024; Gazette of India, 2023). Collaborations among government agencies, certifiers (e.g., VERRA, Gold Standard), and R&D organizations are essential for transparent measurement, reporting, and verification (Singh & Chaturvedi, 2023).

Presently, India ranks second globally in agricultural carbon credit projects with 46 active initiatives under VERRA's Agricultural Land Management (ALM) category (Nozaki, 2021). Effective policy design, adaptive governance, and financial inclusion can ensure agriculture remains both a livelihood base and a climate change solution hub.

5. ROLE IN SUSTAINABLE AGRICULTURE PRACTICES AND FUTURE INNOVATION

Carbon markets reinforce climate-smart agriculture by rewarding low-emission practices such as minimum tillage, cover crops, biochar use, and agroforestry (Cariappa et al., 2024). These methods enhance biodiversity, soil health, and water efficiency. Future innovation focuses on precision nutrient management, IoT-based soil sensors, AI carbon modeling, and blockchain-enabled traceability (Boumaiza et al., 2024). Start-ups like Ground Up in India are developing biochar-based carbon-removal credits, linking sustainability with rural employment (Durham University, 2024). Scaling these technologies can make carbon markets more accurate and inclusive.

6. POLICY INSTRUMENT CONNECTING INDIAN FARMERS TO CARBON AND GREEN MARKETS

India has launched multiple policy instruments to connect farmers and agri-supply chains with environmental markets, including carbon and green credits, with frameworks now in place for standardized project development and potential revenue streams for smallholders. These span market design through the **Green Credit Programme (GCP)** (MoEFCC, 2023), agriculture-specific carbon protocols under **ICAR-CRIDA** (ICAR-CRIDA, 2025), climate-smart scheme linkages such as **NMSA** and **NICRA** (TERI, 2024), financing pilots led by **NABARD** (Farmonaut, 2025), and enabling incentives for participation and capacity building (Just Agriculture, 2024).

6.1 Green Credit Programme (2023)

- The **Green Credit Programme (GCP)** is a national, market-based mechanism notified under the Environment (Protection) Act, 1986, to incentivize voluntary environmental actions and enable trading of "green credits" from activities such as tree plantation, sustainable agriculture, water conservation, and waste management (MoEFCC, 2023; Vikaspedia, n.d.).
- Operationally, degraded land parcels are identified and registered; after verified restoration or plantations reaching milestones, green credits are issued and can be traded on a designated platform administered under **MoEFCC's framework**, with **ICFRE** and **State Forest Departments** supporting implementation and verification (Tropentag, 2024; MoEFCC, n.d.).
- Methodologies for calculating credits have been issued for tree plantation, with ongoing expert debate on ecological safeguards and integration with CSR/ESG and compensatory afforestation obligations, indicating an evolving rulebook that may impact agri-linked activities and aggregation models

(VisionIAS, 2025; Mongabay-India, 2024).

6.2 VCM in Agriculture Protocol (2025, ICAR-CRIDA)

- The **ICAR-CRIDA policy paper (2025)** outlines a Framework for the Voluntary Carbon Market (VCM) in the agriculture sector and an Accreditation Protocol for Agroforestry Nurseries to standardize project development and planting material quality for agroforestry-based credits (ICAR-CRIDA, 2025; Press Information Bureau, 2024).
- It emphasizes MRV rigor, development of Tier-2/3 emission factors, and methodologies for major agri-practices, noting over 140 India-linked agriculture land management projects listed in the Verra registry and the need to reduce transaction costs for farmer participation and fair revenue sharing (ICAR-CRIDA, 2025).
- The framework's goal is to enable small and medium farmers to access VCM revenues by adopting sustainable practices that sequester carbon or reduce emissions, with **ICAR** and **NARES** leading technical backstopping and capacity building (Press Information Bureau, 2024).

6.3 NMSA Linkages to Credits

- The **National Mission for Sustainable Agriculture (NMSA)** promotes climate-smart practices such as conservation agriculture, integrated nutrient and water management, and agroforestry, which align with credit-generating activities in VCM and green credit pathways as methodologies mature (TERI, 2024; Just Agriculture, 2024).
- **TERI (2024)** highlights the project cycle for farm credits—adoption, measurement, MRV, certification (e.g., Verra/Gold Standard), issuance, sale, and revenue distribution—offering a blueprint for aligning NMSA-supported practices with marketable units.
- This linkage positions **NMSA** as a feeder for scalable, standardized agri-carbon and agroforestry projects integrated with national frameworks and voluntary registries (Just Agriculture, 2024; TERI, 2024).

6.4 NICRA and Pilots

- The **NICRA agenda** supports research and pilots on climate-resilient technologies that underpin robust MRV and lower-cost baselines for agriculture carbon projects, serving as a pipeline for scalable VCM interventions (ICAR-CRIDA, n.d.; ICAR-CRIDA, 2025).
- Such pilots inform localized emission factors and practice-specific methodologies, a prerequisite that **ICAR-CRIDA (2025)** identifies as essential for credible and farmer-friendly VCM participation at scale.
- By bridging research and field deployment, **NICRA** helps de-risk aggregation models and improves verification readiness for farmer groups (ICAR-CRIDA, n.d.).

6.5 NABARD-Backed Aggregation Pilots

- Development finance support is emerging for farmer aggregation into carbon initiatives, exemplified by pilots like the **Karnataka mango project**, which uses concessional finance and capacity-building to meet MRV and certification thresholds (Farmonaut, 2025; ICAR-CRIDA, 2025).
- Such models address high upfront costs and coordination barriers for smallholders, improving the feasibility of credit monetization and equitable benefit-sharing at **FPO/cluster levels** (Farmonaut, 2025).
- Integration with **extension systems** and **ICAR protocols** can further standardize farmer onboarding and data systems for verifiers (ICAR-CRIDA, 2025).

6.6 Fiscal and Enabling Incentives

- Beyond direct market instruments, enabling measures include tax benefits, credit subsidies, and capacity building to encourage participation in environmental markets and to cover MRV, certification, and aggregation costs that otherwise deter smallholders (TERI, 2024; Just Agriculture, 2024).
- Public frameworks encourage cross-ministry collaboration to simplify farmer access to VCM, with **MoAFW** and **MoEFCC** roles converging through the **GCP** and agriculture-specific protocols (MoEFCC, 2023; ICAR-CRIDA, 2025).
- As methodologies expand to sustainable agriculture within GCP and align with VCM standards, fiscal incentives can catalyze faster mainstreaming of farm-level projects (MoEFCC, n.d.; TERI, 2024).

Additional Relevant Initiatives

- The **GCP** explicitly lists "sustainable agriculture" among covered activities in its program scope, creating a national pathway parallel to voluntary registries for practices like agroforestry, soil health improvement, and water-use efficiency (Tropentag, 2024; Vikaspedia, n.d.).
- Analytical reviews note that GCP credits may be used by entities to meet certain obligations or ESG/CSR aims, while ongoing technical refinements are expected to clarify durability, additionality, and exchange rules vis-à-vis carbon credits (Mongabay-India, 2024; CEERA-NLSIU, 2024).
- Knowledge partners such as **TERI** contribute methodologies and implementation models that can be adopted by states and **FPOs** to structure investable projects and farmer revenue distribution mechanisms (TERI, 2024).

Practical Pathway for Farmers and FPOs

- Aggregation via **FPOs**, adoption of **ICAR-aligned practices**, baseline mapping with RS-GIS, and selection of an accredited standard (e.g., Verra) remain core steps to generate tradable units and negotiate offtake, with public schemes lowering costs and risks (TERI, 2024; ICAR-CRIDA, 2025).
- Where **GCP methodologies** recognize sustainable agriculture, entities may pursue green credits domestically; where **VCM economics** are stronger, projects

can target international registries while leveraging **NMSA/NICRA** support for MRV readiness (MoEFCC, 2023; Just Agriculture, 2024).

- Close coordination with **NABARD/State missions** can unlock concessional finance for MRV and verification, easing entry for smallholders into carbon markets (Farmonaut, 2025).

MERITS AND DEMERITS OF CARBON TRADING

Carbon trading offers tangible income and resilience benefits for farming communities but also faces cost, access, and integrity challenges that can limit impact without strong governance and farmer-centric design.icar-crida+4

MERITS

- Creates financial incentives for sustainable farming by monetizing emission reductions and removals, enabling producers to earn from practices like agroforestry, conservation tillage, and improved nutrient management that generate verified credits and supplemental revenue streams alongside crops.openknowledge.worldbank+1
- Enhances soil health, water retention, and biodiversity when credits are tied to nature-based practices that increase soil organic carbon, improve infiltration, and support on-farm habitats, aligning with high-integrity methodologies that reward co-benefits in land use systems.bain+1
- Diversifies rural income and reduces climate vulnerability by adding a performance-based income source that is less correlated with local weather shocks, while channeling finance to resilience-enhancing practices that stabilize yields over time.saiia+1
- Encourages technological innovation and data-driven management as projects adopt digital MRV, remote sensing, and farm-level record systems to quantify outcomes, which accelerates adoption of precision practices and strengthens agronomic decision-making.climate-change+1

DEMERITS

- High MRV and certification costs increase entry barriers because accurate measurement, reporting, and verification in dispersed smallholder settings require standardized methods, field data, and audits that are expensive relative to credit revenues at current market prices.icar-crida+2
- Limited awareness and access for smallholders persists as many farmer groups lack technical assistance, finance, and market intermediation to participate, prompting initiatives to build capacity but leaving inclusion gaps in many regions.cashcoalition+2
- Risk of greenwashing and price volatility undermines confidence, as integrity concerns have depressed average VCM prices and market value, while public debates over claims and credit quality create uncertainty for project developers and buyers.ppp.worldbank+3
- Unequal benefit distribution without strong governance can occur when intermediaries, transaction costs, and information asymmetries capture value,

requiring clear rules, buyer integrity frameworks, and farmer-first contracting to ensure fair revenue sharing.

8. CONCLUSION

This study shows that agricultural carbon credits can align farm economics with climate mitigation when three conditions are met: high-integrity measurement, inclusive aggregation, and predictable market access for smallholders. Evidence around improved agricultural land management, including zero/minimum tillage, diversified rotations, agroforestry, biochar, and efficient water-nutrient management, confirms dual gains—measurable emission reductions and resilient productivity—once verified under robust standards such as Verra's VM0042 and AFOLU approaches. India's enabling architecture—the Green Credit Programme for domestic "green" actions and ICAR-CRIDA's agriculture VCM framework—can lower transaction costs, standardize methodologies, and channel finance to FPO-led clusters that negotiate fair offtake and revenue sharing. The practical next step is farmer-centric execution: baseline mapping, digital MRV, transparent contracts, and grievance mechanisms that ensure a majority of credit value reaches producers while safeguarding permanence and additionality. Implemented this way, carbon trading becomes a credible bridge between regenerative agriculture and rural prosperity, turning documented climate-positive practices into durable, equitable livelihoods at scale.

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Integrated Nutrient Management in Cotton for better crop productivity under North Indian Scenario

Introduction:

Cotton is major fibre and commercial crop India, being grown all three zones i.e. North Zone, Central and South Zone. Soils of North Zone are defined by loamy-sandy nature with alluvial type. Cotton being a deep rooted crop utilizes large quantities of nutrients from the soil profile. Nutrient management in cotton is complex due to synchronized or parallel vegetative and reproductive active growth phases. Fertilizers are being applied for last many years by farmers but in traditional manner without profiling soil status for optimum requirement. This has led to lower yields and spatial variation among the nutrients under the similar management situations under North Zone scenario.

The *Bt* cotton hybrids produce relatively more number of fruiting bodies and to retain more bolls with more boll weight and hence it needs higher quantity of nutrients compared to Non Bt cotton in general. Intensively cultivated soils are being depleted with available nutrients especially secondary and micronutrients. In expectation to get more production, farmers are in practice of using more chemical fertilizers in North India. Adequate and balanced nutrition holds the key to sustain the yield and quality of cotton. While sub-optimal nutrition reduces the yield potential of crops on other hand excessive application of nutrients adversely impacts the profitability due to increase in cost of cultivation. Applications of access nutrients leads to contamination of groundwater, excessive vegetative growth in the crop and associated insect-pest problems.

Balanced nutrient management plays an important role in yield formation in any crop. Plant nutrients play various roles in the formation, partitioning, and utilization of photosynthates in plants. Deficiencies of plant nutrients cause various disorders or deficiency symptoms due to improper nutrient supply. A balanced nutrient management program with macro and micro nutrients should be one of the most important factors for production of higher cotton yields of good quality. An optimal nutrient management strategy should avoid its negative ecological impact and undesirable effects on the sustainable cotton based cropping systems. Hence, it is imperative to establish an integrated nutrient management program which should be both economically and environmentally friendly in nature.

1.2 Economic Imperatives and Market Projections

Integrated nutrient management (INM) in cotton involves using a combination of chemical fertilizers, organic matter, and soil amendments to optimize nutrient (Macro & Micro nutrients both) supply to the crop. The goal of INM is to improve soil fertility and plant growth while reducing negative environmental impacts and economic costs. INM practices in cotton can include:

I. Soil testing to determine nutrient deficiencies and scheduling the appropriate fertilizers.

II. Crop rotation and intercropping with other suitable crops to improve soil health and nutrient cycling.

III. The use of compost, FYM, green manures and other organic matter to improve soil fertility and soil health.

IV. The application of balanced fertilizers with appropriate methods to supply adequate nutrients at critical growth stages.

INM practices can help to increase cotton yields and fibre quality, reduce fertilizer inputs and costs and minimize the negative impacts of fertilizer use on the environment.

1. **Balanced nutrition management and nutrient demand in cotton:**

Balanced nutrition management with economically optimum fertilizer rates for high-yielding cotton crop is normally the most important work in integrated cotton nutrition management, and the knowledge of nutritional status of the crop is fundamental in determining fertilizer recommendations to improve crop production. Generally, cotton nutrient uptake is relatively low during the early growing season, and significantly increases after flowering and during early boll development. A few weeks after flowering, the plant attains its peak nutrient uptake rate and the total demand reaches a maximum as the bolls begins to mature. To achieve the greatest efficiency of nutrient uptake and utilization, fertilizer applications should be synchronized to meet crop demands at different growing stages in cotton.

Macronutrients such as N, P, and K are the most important elements for cotton production, which are often considered in nutritional management. However, micronutrient problems have been constraining cotton production due to over emphasis on macronutrients, decreased use of organic manure, less recycling of crop residues in soil, and introduction of high yield varieties / hybrids. A reduction in yield of seed-cotton due to imbalanced application of micronutrients, particularly Zn and B, has been frequently reported on calcareous soils. Cotton is regarded as a particularly Zn-sensitive crop, and Zn deficiency normally appears when cotton plants grow in high pH soils and with high rates of P application. Thus farmers have to apply the fertilizers as per nutrient requirement in that particular area of cotton cultivation. The nutrient deficiency symptoms of various nutrients in cotton are shown in the Table 1.

Table 1 Functions and deficiency symptoms of various nutrients in cotton

Name of the nutrient	Functions in cotton plants	Deficiency symptoms
Nitrogen (N)	Nitrogen is major plant nutrient which control new growth, nutrient uptake and prevents abscission of squares and bolls. Nitrogen increases plant height, monopodial and sympodial branches per plant, harvested bolls per plant and seed cotton yield. It improves the quality of lint viz., fibre length, bundle strength and fibre fineness.	Symptoms of cotton N deficiency are readily identifiable, which normally appear on older leaves first, and then rapidly move from older to younger parts of the plants. At the beginning, old leaves become uniformly pale green, pale yellow, then turn yellow, and develop brown necrosis areas. Leaf expansion is slowed down by N deficiency.
Phosphorus (P)	Phosphorus is the second key nutrient for every crop including cotton. It stimulates early growth and root formation, hastens maturity, promotes	Deficiency symptoms of this nutrient appear first on lower or older leaves and further upwards on a stalk. The

	seed production and makes plants hardy.	plant become dark green and stunted in growth where the blooming and fruiting got delayed. A purple pigmentation may develop on the leaf margins and proceed into inter-veinal tissues of leaves in the severe cases, and then older leaves will be in chlorosis, necrosis, and abscission.
Potassium (K)	Potassium is the third key nutrient in the cotton life cycle. Potassium improves plant's ability to resist disease, cold and drought stresses and also helps in the production of carbohydrates. Potassium remains in an ionic form in the plant cells and tissues and controls osmo-regulation. It plays an important role in fibre development and the turgor-driven expansion of fibre cells and ultimately determines the fibre length.	The deficiency symptoms of potassium often occur first at the bottom of the plant on the older, lower, or mature leaves. The leaves become brown-reddish, the tips of leaves curl and breakdown. Normally, K deficiency symptoms may develop on mature leaves of the upper canopy after flowering commences K deficiency symptoms can also be found on young cotton leaves at the top of the plant and spread from the top to the bottom during flowering and boll development.
Magnesium (Mg)	Magnesium is an ingredient of	Leaves become reddish and the

	chlorophyll, helps in the translocation of starch within the plant and is essential for formation of oils and fats.	veins remain green or leaf cupping and intervening chlorosis and it starts in young leaves. The typical symptoms first present on older and mature leaves.
Calcium (Ca)	Calcium helps in the movement of carbohydrates in plants and is essential to healthy cell walls and root structure. **Calcium** improves cell wall strength and integrity and is crucial for overall new cell development.	During this deficiency the cotton crop affected during the maturity stage. The leaf of cotton becomes crinkled with poor root growth. The upper leaves and squares & young bolls become dry.
Sulfur (S)	Sulfur helps in the formation of oils and parts of protein molecules in the plants.	The deficiency symptoms are first evident and more pronounced on younger leaves, while older leaves remain green. Young leaves become light green to yellow in color.
Iron (Fe)	Iron is essential for formation of chlorophyll& releases energy from sugars and starches.	The deficiency symptoms show yellowing of top cotton leaves. Chlorosis first appears in the young leaves in the form of light yellowish spots between the veins, and then the younger leaves turn pale green to pale yellow, while the older leaves remain green

		and normal.
Zinc (Zn)	Zinc is an essential constituent of several enzymes, controls synthesis of indoleacetic acid – an important growth regulator in plants.	The plant also shows a shorter appearance. A typical Zn deficiency symptom of "little leaf" and inward curling of top leaves is evident in cotton. The main symptoms in cotton are chlorosis and malformation of young leaves and a general bronzing in the first true leaves.
Boron (B)	Boron helps in the assimilation of calcium in plants. Boron is required in extremely small quantities and excessive boron is very toxic. Boron plays an important role in fruiting and blooming.	B- deficiency symptoms appear at the apex of the plant and on the fast growing leaves; dieback of terminal growth, excessive shedding of squares and young bolls.
Copper (Cu)	Copper promotes formation of Vitamin A in plants. Copper is required in extremely small quantities and excessive copper is very toxic.	Inter-veinal chlorosis of the leaves. The young leaves fail to expand and the leaf color turns to bluish green with Cu deficiency. The apical part of the young leaflets turns white and necrotic.

2. Biofertilizers in integrated nutrient management for cotton

The major attraction of using bio-fertilizers in integrated nutrient management system is to convert the unavailable nutrients to available form which is readily available and easily accessible by the plants. Biofertilizers improves soil physical as well as biological properties and sustain soil fertility by providing nutrients in available forms to the plants. This is one of the important component of INM which aims to improve the stock of plant nutrients in the soilsimproving the efficiency of plant nutrients, thus, limiting losses to the environment. Thus, integrated nutrient supply / management aims at maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of benefits from all possible sources of plant nutrients in an integrated manner.

3. Recommendation regarding Fertilizer Applications for cotton under North-Western Indian conditions:

Fertilizer should preferably be applied on the soil test basis. In the absence of soil test report, the fertilizer recommendations should be followed for medium fertility soils are as mentioned in Table 2.

During raising the cotton crop in fields, following important recommendations should to be followed as per need:

- Omit application of phosphorus to cotton when it follows wheat which had received recommended dose of phosphorus. Where 67.5 kg DAP is used, reduce the urea dose by 25 kg (under Punjab conditions).
- Apply 50 kg muriate of potash and 25 kg zinc sulphate heptahydrate (21%) or 16.25 kg zinc sulphate monohydrate (33%) per hectare to cotton in light soils.
- Drill all phosphorus at sowing. Apply half nitrogen at thinning and remaining half at the appearance of flowers.
- If the soil is low in fertility, the first half dose of nitrogen may be applied at sowing instead of at thinning.
- Apply 1kg boron (10 kg borax) per hectare at sowing in boron deficient soils.
- To get higher yields, give 4 sprays of 2% potassium nitrate (13:0:45) at weekly intervals starting at flower initiation.

- For high yield and management of leaf reddening in Bt cotton, give 2 sprays of 1% magnesium sulphate (2.5 kg magnesium sulphate in 250 litres of water per hectare) at 15 days interval during full bloom and boll development stages.

Conclusion

Mineral nutrients possess important functions in plant physiology, which positively impacts the growth, development, and yield of cotton. Nutrient balance plays a substantial role in improving cotton nutrient management. Both macro and micronutrients and organic and inorganic nutrients should be taken into account to establish an effective nutrient management program for cotton. Nutrient deficiencies in cotton usually accompany with a series of symptoms such as chlorosis, stuntedness, abnormality, and influence cotton health and disease resistance. Prediction of cotton nutrient requirements according to the genotype and targeted yield, understanding nutrient supply in relation to nutrient availability, nutrient cycling, and foliar fertilizers, and combining soil testing and plant analysis during the cotton growing season can help to achieve precise nutrient management under most situations. Integrated nutrient management including soil and foliar applications and water and nutrient management is helpful in achieving economically and environmental friendly cotton production. Further improvements in nutrient use efficiency would require the consideration of technologies enabling the monitoring of plant nutrient status during the growing season, as well as more precise delivery of nutrients and water to the cotton root zone through drip irrigation.

Table 2 Fertilizer and plant nutrient recommendation for cotton under North-Western Indian conditions

Sr. No.	States	Fertilizer/nutrient		Desi Cotton (*Desi kapas*)		American Cotton (*Narma*)	
				Varieties	Hybrids	Varieties	Bt/Non Bt Hybrids
1.	Haryana	Nutrient (kg / ha)	Nitrogen	50		87	175
			Phosphorus P_2O_5	-	Same as American cotton hybrids	30	60
			Potash	-		-	60
		Fertilizer (kg / ha)	Urea	112		187	375
			DAP	-		67	135
			SSP	-		187	375
			MOP	-		-	100
2.	Punjab	Nutrient (kg / ha)	Nitrogen	75		75	105
			Phosphorus P_2O_5	30		30	30
			Potash	-		-	-
		Fertilizer (kg / ha)	Urea	162		200	225
			DAP	67		67	67
			SSP	187		187	187
3.	Rajasthan	Nutrient (kg / ha)	Nitrogen	90		100	150
			Phosphorus P_2O_5	20		40	40
			Potash	-		20	-
		Fertilizer (kg / ha)	Urea	195		217	325
			DAP	45		87	87
			SSP	125		250	250
			MOP	-		35	-

#Source: Package of Practices of Agricultural Universities of respective states.

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MECHANISM OF HYPERACCUMULATION OF CHEMICAL ELEMENTS IN PLANTS

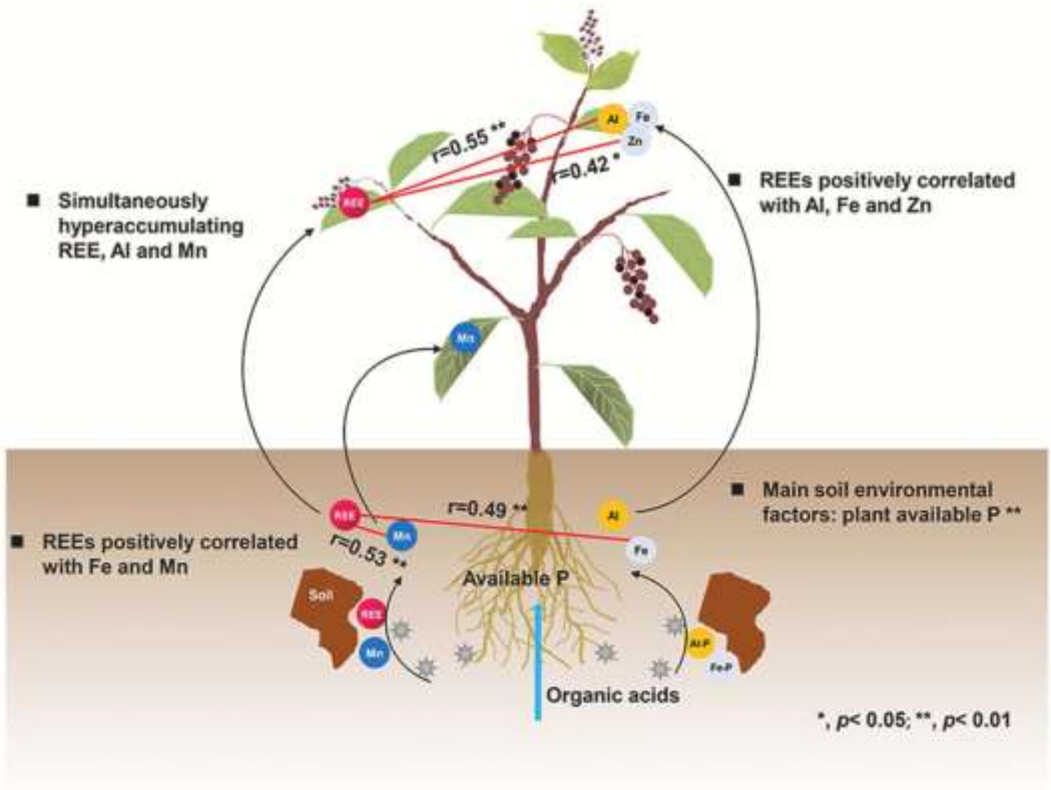
Understanding Plant Adaptation and Resilience

INTRODUCTION TO HYPERACCUMULATION

Definition of hyperaccumulation: **Hyperaccumulation** refers to the ability of certain plants to absorb and accumulate high concentrations of specific metals or other elements from the soil, often at levels significantly higher than those found in typical plants. This phenomenon is especially noted for heavy metals like nickel, zinc, and cadmium, as well as certain non-metals.

Hyperaccumulator plants have specialized mechanisms that enable them to tolerate and store these elements without suffering from toxicity. These plants are of interest for various applications, including:

- **Phytoremediation:** Using plants to clean up contaminated soil and water by absorbing pollutants.
- **Soil Restoration:** Restoring metal-contaminated sites to a healthier state.
- **Biorecycling:** Recovering valuable metals from waste.



OVERVIEW OF CHEMICAL ELEMENTS

Commonly hyperaccumulated elements are heavy metals like Zn, Ni, Pb, and essential nutrients like Cu. Nickel is the element most often hyperaccumulated: about 75% of hyperaccumulator taxa are Ni hyperaccumulators.

There are also substantial numbers of hyperaccumulators of Co, Cu and Se, along with smaller numbers that hyperaccumulate As, Cd, Mn, Tl and Zn.


NICKEL


ZINC


LEAD


COBALT


COPPER


SELENIUM


ARSENIC


CADMIUM


MANGANESE

They displace the vital nutritional minerals from their original place, thereby, hindering their biological function. It is, however, impossible to live in an environment free of heavy metals.

There are many ways by which these toxins can be introduced into the body such as consumption of foods, beverages, skin exposure, and the inhaled air.

The removal of single heavy metals like Co and Zn from aqueous solutions using various low-cost adsorbents (Fe_2O_3, Fe_3O_4, FeS, steel wool, Mg pellets, Cu pellets, Zn pellets, Al pellets, Fe pellets, and coal) was investigated.


Fe_2O_3


Fe_3O_4


FeS


Al Pellets


Mg pellets


Coal

USAGE OF HEAVY METALS AND ITS EFFECTS

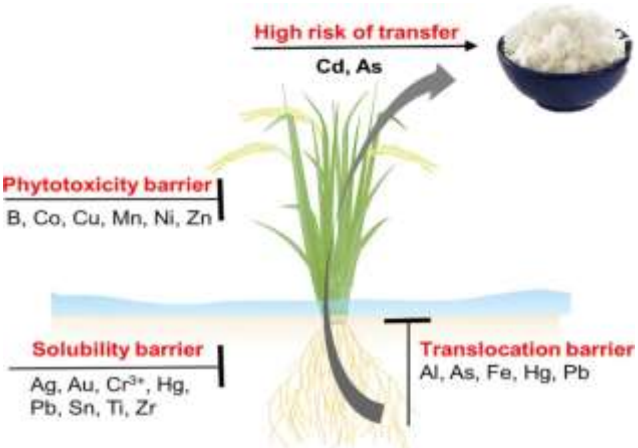
Heavy Metals and Ecosystem contaminations of land resources continue to be the focus of numerous environmental studies and attract a great deal of attention worldwide. This is attributed to non-biodegradability and persistence of heavy metals in soils.

In order to identify spatial relationship of heavy metals in soil-rice system at a regional scale, 96 pairs of rice and soil samples were collected from Wenling in Zhejiang province, China, which is one of the well-known electronic and electric waste recycling centres.

The results indicated some studied areas had potential contaminations by heavy metals, especially by Cd. The spatial distribution of Cd, Cu, Pb, and Zn illustrated that the highest concentrations were located in the northwest areas and the accumulation of these metals may be due to the industrialization, agricultural chemicals and other human activities.

It is generally believed that herbal and natural products are safer than the synthetic or modern medicines but even some indigenous herbal products contain heavy metals as essential ingredients.

Heavy metal contamination in herbal medicines is a global threat to human beings



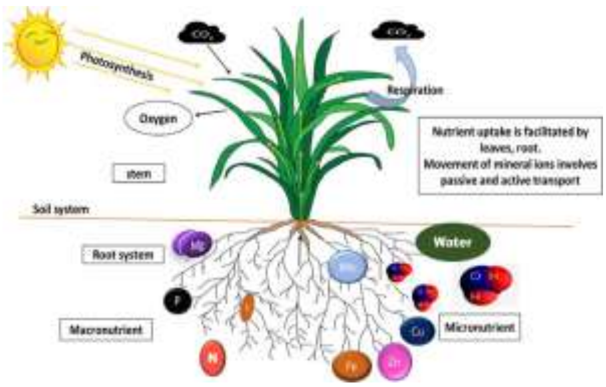
especially at levels above known threshold concentrations. The concentrations of five heavy metals cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg) and copper (Cu) were investigated using Inductively Coupled Plasma Optical Mass Spectrometry (ICP-MS) with 1773 samples around the world.

According to Chinese Pharmacopoeia, 30.51% (541) samples were detected with at least one over-limit metal. The over-limit ratio for Pb was 5.75% (102), Cd at 4.96% (88), As at 4.17% (74), Hg at 3.78% (67), and of Cu, 1.75% (31). For exposure assessment, Pb, Cd, As, and Hg have resulted in higher than acceptable risks in 25 kinds of herbs.

The maximal Estimated Daily Intake of Pb in seven herbs, of Cd in five, of Hg in four, and As in three exceeded their corresponding Provisional Tolerable Daily Intakes. In total 25 kinds of herbs present an unacceptable risk as assessed with the Hazard Quotient or Hazard Index.

MECHANISMS OF UPTAKE

Mineral uptake is the process in which minerals enter the cellular material, typically following the same pathway as water.



The most normal entrance portal for mineral uptake is through plant roots. During transport throughout a plant, minerals can exit xylem and enter cells that require them.

Mineral ions cross plasma membranes by a chemiosmotic mechanism. Plants absorb minerals in ionic form. The uptake of nutrients occurs at both the roots and the leaves.

Ions may be taken up by the plant cells by two methods:

- Passive Absorption

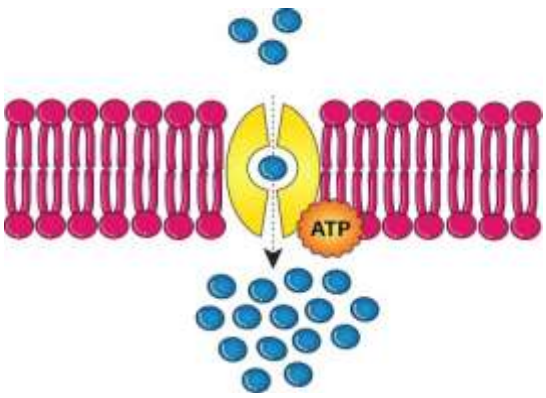
- Active Absorption

Together, these transport mechanisms enable plants to regulate ion concentrations within their cells, absorb essential nutrients from the soil, and maintain the electrochemical gradients necessary for various physiological processes.

ACTIVE ABSORPTION

It is the absorption of minerals with the direct expenditure of metabolic energy.

During the active absorption of minerals, ions from the outer space of the cell move into the inner space and it generally occurs against the concentration gradient. Hence it requires metabolic energy and this energy is obtained from the cell's metabolism either directly or indirectly.

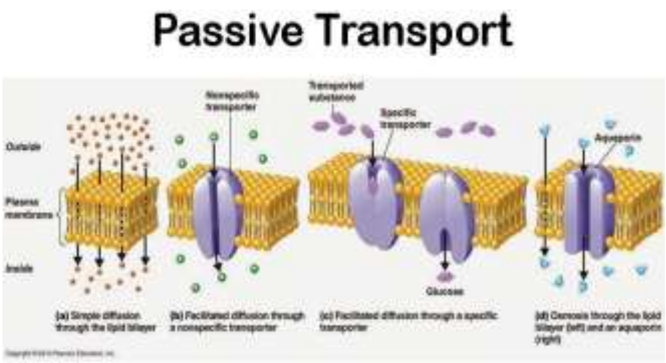


All minerals cannot be transported passively in the roots as the concentration is low in the soil and moreover they are present as a charged particle, which cannot cross the cell membrane. These are actively transported in the roots using energy stored as ATP.

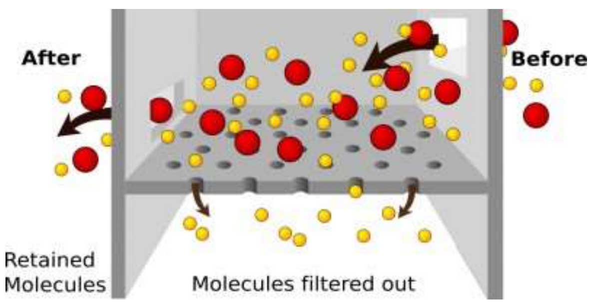
Minerals are transported by specific proteins present in the membrane of the root hairs. Transport proteins are embedded in the plasma membranes of endodermal cells and control the type and amount of solutes reaching the xylem. From roots, minerals are then transported to all the other parts by transpiration pull.

PASSIVE ABSORPTION

Passive transport is the fundamental movement of ions and other molecular substances within the cells along the concentration gradient, without any external energy. It is also known as passive diffusion.

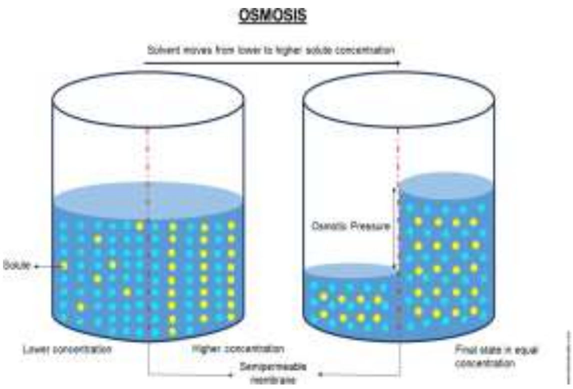


Simple diffusion: Diffusion is the movement of substances from a region of higher concentration to a lower concentration. The difference in the concentration of the two areas is termed a concentration gradient and the process of diffusion continues until this gradient neutralizes.



Facilitated diffusion: Facilitated diffusion is the passive transportation of ions or molecules across the cell membrane through specific transmembrane integral proteins. The molecules, which are large and insoluble require a carrier substance for their transportation through the plasma membrane. This process does not require any cellular or external energy.

Filtration: The selective absorption of nutrients in the plants is an example of filtration. This process does not require any energy and takes place along the concentration gradient. In the process of filtration, the cell membrane permits only those substances which are soluble and could easily pass through its pores. Ion channels and aquaporins are some examples of facilitated diffusion.



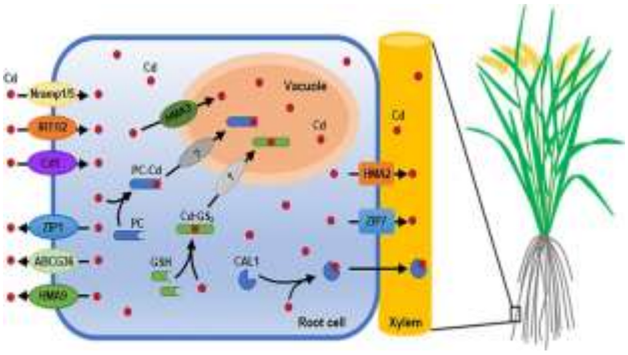
Osmosis: In the process of osmosis, water and dissolved minerals pass through a selectively permeable membrane in order to balance the concentration of other substances. Osmosis is affected by the concentration gradient and temperature. The greater the concentration gradient, the faster the rate of osmosis. Also, rate of osmosis increases with increase in temperature.

STORAGE MECHANISM

Hyperaccumulators are plants with specific roots that are efficient in the absorption of large amounts of metals from the soil.

Translocation: After the metal is taken in through the leaves or the root, it can be translocated from the roots through the xylem to the upper regions of the plant where it is often deposited in the stem leaves.

Vacuolar Sequestration: In plants, vacuoles sequester and store such metals as nickel or cobalt to prevent the cell from being damaged.



Cytoplasmic Storage: serves as a metallic collection area for the proteins phytochelatin and metallothionein that have bound metals requiring detoxification or protection from cellular damage.

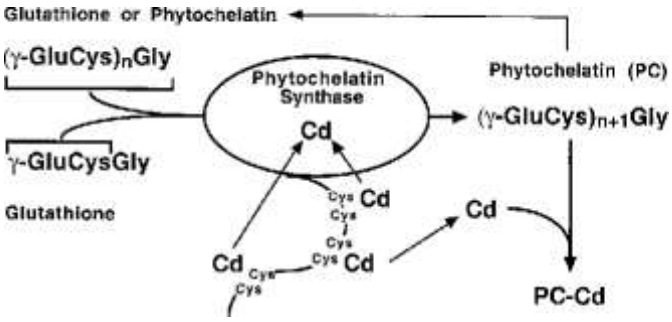
Parietal Sequestration: Metals are absorbed by cell wall components, part of the cytoplasmic storage system which prevents additional storage within the cytoplasm.

PHYSIOLOGICAL ADAPTATIONS

Plants possess specialised roots and proteins that aid in the accumulation of metals into the them.

Exporting Metabolites: These plants release organic acids that aid in the solvation of metals which is beneficial in their uptake. Solvation is the interaction of a solute with the solvent which leads to stabilization of the solute species in the solution.

Transport Proteins: Metals are bound to proteins known as phytochelatins, which remove or reduce toxicity, to aid in metal sequestration.



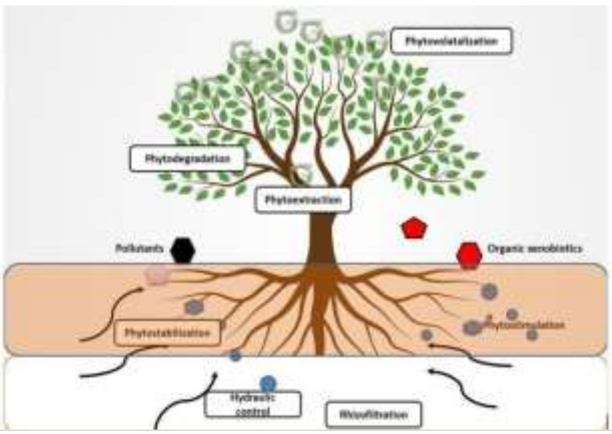
Protective Measures: Plants contain large amounts of metal ion in vacuoles, so as to sequester them from critical cellular processes that may lead to cellular injury. Vacuoles restrict movement of heavy metals and help in avoiding their toxic effects.

Damage Recovery: Hyperaccumulators have ways to defeat the negative impacts of metals and resuming their usual processes. These include metal detoxification, antioxidant production, efficient repair mechanisms and chelation and transport proteins.

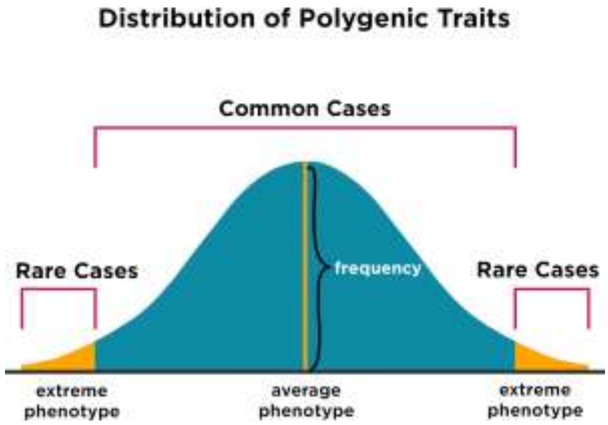
GENETIC BASIS OF HYPERACCUMULATION

Metal Transporter Genes: Within hyperaccumulator plants, there exist specialized genes that encode transport proteins so as to facilitate the uptake of metals from the soil.

Detoxification Proteins: A metallothionein and phytotechnologist gene known is involved in metal binding and its ionic forms reducing the impact of toxin.



Stress Response Genes: These plants also have genes in them that are known to be essential for the synthesis of certain antioxidants that are helpful in detoxifying high levels of oxidative stress.



Regulatory Transcription Factors: Genes that induce their expression in the presence of metal - metal binding proteins bind continuously up to a set point of maximum saturation.

Polygenic Trait: Hyperaccumulation is a polygenic trait owing that the several genes that control the tolerance to high metal level and metal accumulation are numerous, hence variations within and among different species.

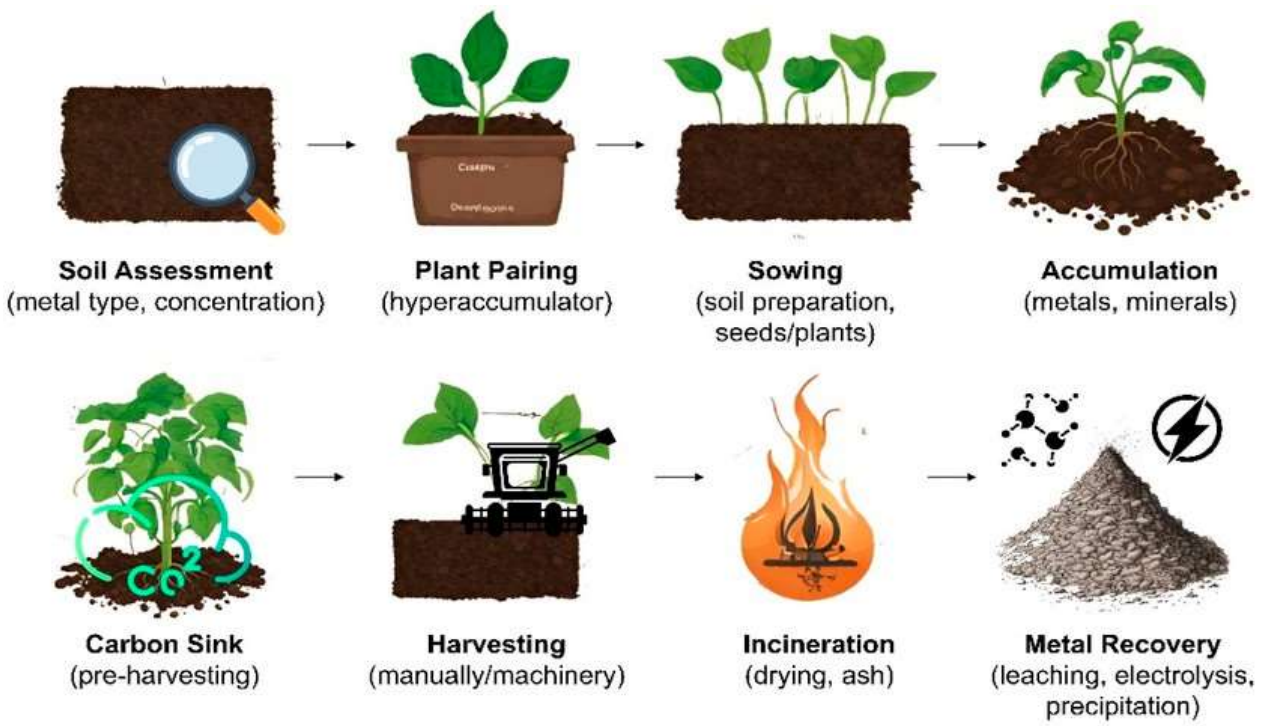
ECOLOGICAL IMPLICATIONS

Phytoremediation: Contaminated soils can be decontaminated after they have been fully stored and absorbed into biomass. Bioremediation plants can absorb and remove toxic compounds from soil and water

Nutrient Cycling: Ecosystems dominated by hyperaccumulators tend to extend limited precious metals and other vital nutrients deposits.

Habitat Creating: Such distinctive habitats can be formed enabling the organisms to develop heavy metal resistant specialized non-competitive communities.

The accumulation of metals alters the lower trophic levels as well as their predators thus



brings significant changes to the food web.

Evolutionary Pressure: Some of the individuals population structures can have an impact on other neighbouring populations causing changes to the population structure of that particular population.

APPLICATIONS IN AGRICULTURE

Potential for increasing crop resilience to heavy metal stress: Agricultural researchers can uncover genetic features and metabolic mechanisms that contribute to crop resilience. This exposes crops to significant metal stress.

Phytoremediation: Hyperaccumulators can be used to clean up heavy metal contaminated soil. They can accumulate heavy metals in their leaves at levels 100-1000 times higher than non- hyperaccumulators.

Phytomining: Hyperaccumulators are often used to extract metals from the soil. The plants are grown, then the biomass is harvested, dried, and incinerated to create a high-grade bio-ore.

Food fortification: Many of the metals that hyperaccumulators can accumulate are also essential nutrients for humans. Thus, hyperaccumulators are often used to make food products that would help to cure deficiencies.

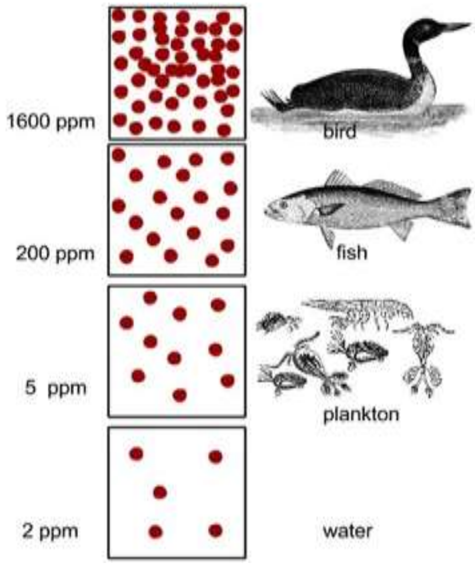
CHALLENGES AND LIMITATIONS

Growth rate and biomass production: As compared to regular crops, these plans grow slowly and produce less biomass. They also take a longer time to clean up the soil. Thus, the

overall productivity in such plants is lower than other crops.

Environmental and ecological risks: Hyperaccumulators when consumed by animals or humans could lead to harmful effects. It may also lead to bioaccumulation in food chains. So, one has to be careful while planting these plants.

Economic feasibility of utilizing hyperaccumulators: If we take a look at the financial aspect, it could be quite expensive. As these plants grow in a slow manner, it may take time to get the desired output. So, hyperaccumulators can only be used for long term projects.



Risk of Biomagnification: These plants after being eated by organisms lower in the food pyramid, leads to accumulation of large amounts of these toxic heavy metals in the organisms higher in the food pyramid. This is known as biomagnification.

CASE STUDY

BRIEF: This case study includes study on hyperaccumulation in Alpine pennycress, (*Thlaspi caerulescens*), a well-known hyperaccumulator of heavy metals, for remediation of contaminated soils.

SITE OVERVIEW:

- **Location:** A former zinc and lead mining region in Southern France.
- **Problem:** The soil in the area was heavily contaminated with high concentrations of Cadmium (Cd) and Zinc (Zn), which lead to poor human health, low agricultural productivity and risks of bioaccumulation.

OBJECTIVES:

- Reduction of levels of Cadmium and Zinc in the soil to manageable levels.
- Exploring the feasibility of using hyperaccumulation as a sustainable and cost-efficient method for soil remediation.

PROCESS:

1. **Planting of *Thlaspi caerulescens*:** The plant was carefully selected for its ability to accumulate high concentrations of zinc and cadmium from the soil. It tolerates and stores up to 30,000 ppm of Zinc and 1,000 ppm of Cadmium in its tissues without suffering from any harmful impacts.
2. **Growth and Harvest Cycles:** Several growth and harvest cycles were carried out over a few years to maximize the extraction of heavy metals. After each cycle, the plants were harvested to prevent the metals from being returned to the soil during decomposition.
3. **Monitoring Soil Metal Levels:** The concentration of Zinc and Cadmium in the soil was measured from time to time for

evaluating the efficiency of remediation.

RESULTS:

Over time, there was significant decrease in cadmium and zinc concentrations in the selected areas. This demonstrated that hyperaccumulation by *Thlaspi caerulescens* could effectively be used to lower heavy metal concentrations in such soils.

CHALLENGES ENCOUNTERED:

- **Slow Progress:** While there was a significant reduction in metal levels, the process was very slow, requiring multiple growth cycles over multiple years for achieving substantial remediation.

- **Plant Stress and Soil Fertility:** As the heavy metal levels decreased, the plants displayed signs of stress, and the soil required additional nutrient management to maintain fertility.

CONCLUSION:

Thus, we can say that hyperaccumulators can be used as a sustainable approach for phytoremediation of soils with high heavy metal concentrations, but the projects need to be long term with substantial financial inputs.

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Heavy metal hyperaccumulating plants: How and why do they do it? And what makes them so interesting?

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FROM INDEXING TO INTELLIGENCE: REDEFINING SOIL QUALITY PREDICTION

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Abstract

Soil quality assessment is critical for sustainable agriculture, but traditional laboratory methods are often slow, expensive, and labour-intensive. This article reviews the evolution of soil quality assessment from traditional statistical indexing to modern, data-driven predictive models. It briefly covers the conventional approach of using a soil quality index (SQI) derived from a minimum data set (MDS), often selected using principal component analysis (PCA). The focus then shifts to the superior predictive power and efficiency of machine learning (ML) and deep learning (DL) algorithms. This review summarises recent successes in using Artificial Neural Networks (ANN), ensemble models like XGBoost, and advanced deep learning frameworks like Convolutional Neural Networks (CNNs) and Spatial-Aware Neural Networks (SANNs). These AI-driven tools, when combined with Explainable AI (XAI) for model transparency, offer a scalable, precise, and interpretable pathway for real-time, data-driven decision support in precision agriculture and sustainable land management.

Introduction

Soil quality is the foundation of a productive and sustainable agricultural system. It is formally defined as the continued capacity of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Doran and Parkin, 1994; Karlen *et al*., 1997). Ensuring soil quality is essential for global food security. Land use changes and intensive management practices such as excessive tillage, have been shown to cause severe soil degradation (De *et al*., 2022; Zeraatpisheh *et al*., 2020).

The challenge for farmers and land managers has always been the difficulty of measuring soil quality. Traditional assessment requires extensive field sampling followed by costly and time-consuming laboratory analyses. To make this process faster, more scalable, and more efficient, researchers are actively seeking precise and effective methodologies, which has led to a significant shift toward the power of data-driven techniques, particularly machine learning (ML) and artificial intelligence (AI) (Babu and Yadavamuthiah, 2023). This article provides a technical review of the evolution from traditional soil quality indexing methods to these modern predictive models.

Methodology

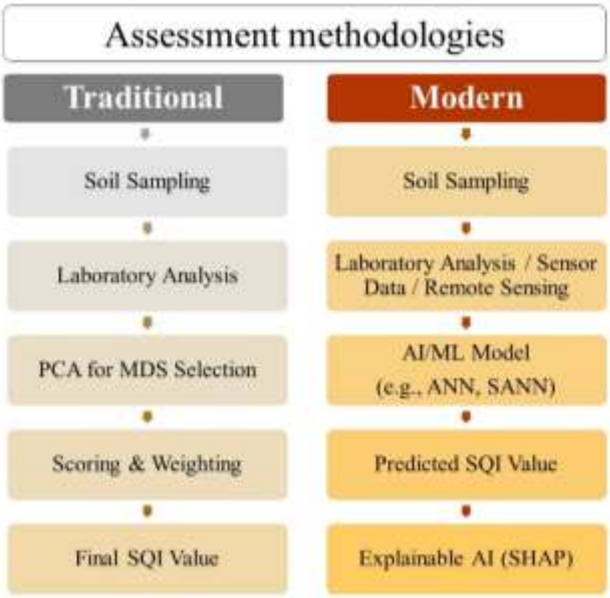

Figure 1 Conceptual flowchart of assessment methodologies

1. The statistical approach (traditional)

For decades, the standard method for quantifying soil quality has been the soil quality index (SQI), which involves collecting extensive soil data (physical, chemical, and biological), and then distilling it into a single, representative score (De *et al*., 2022).

A key step in this process is creating a minimum data set (MDS) (Lenka *et al*., 2022). It is inefficient to measure every soil property, since many soil properties are correlated (e.g., soil organic matter influences bulk density, aggregate stability, and microbial activity) (Simfukwe *et al*., 2021). Principal component analysis (PCA) is a powerful statistical tool used to identify the most critical and representative indicators. PCA groups correlated variables into "principal components" (PCs) (Jameel and Chowdhary, 2025). By identifying the indicators with the highest factor loadings within the most significant PCs (those with eigenvalues >1), researchers can objectively select a robust MDS. The final SQI is then calculated as a weighted sum of these key indicators. While effective, this approach is linear and static.

2. The predictive approach (modern)

Machine learning offers a powerful alternative. ML models are highly effective at learning the complex, non-linear relationships between soil properties that simple statistical models might miss (Babu and Yadavamuthiah, 2023). It is crucial, as soil quality is driven by the intricate, interdependent network of its attributes (Jameel and Chowdhary, 2025). Key models include:

i. **Artificial Neural Networks (ANN):** ANNs are models inspired by the human brain that utilize interconnected "neurons" in layers (input, hidden, and output) to process information and learn complex patterns (Negiş *et al*., 2025; El Behairy *et al*., 2024).

ii. **Ensemble Models:** Models like Random Forest (RF) and Extreme Gradient Boosting (XGBoost) combine predictions from multiple "weaker" models to create a single, highly robust, and accurate result (Jameel and Chowdhary, 2025; Sadasivan *et al*., 2025).

iii. **Deep Learning (DL):** A more advanced class of ML. Convolutional Neural Networks (CNNs) can extract features from soil images or spectral data (Padarian *et al*., 2019). Long Short-Term Memory (LSTM) networks are designed to capture temporal relationships, making them ideal for monitoring changes over time (Babu and Yadavamuthiah, 2023).

iv. **Spatial-Aware Models (SANN):** These advanced networks integrate geospatial data (i.e., latitude and longitude) directly into the model architecture as input features to learn location-based variations (Jameel and Chowdhary, 2025).

Table 1: Comparison of soil quality assessment methodologies

Feature	Traditional SQI (PCA-based)	Modern ML/AI models
Primary Method	Statistical Indexing	Predictive Modelling
Data Handling	Linear relationships (PCA)	Non-linear relationships (ANN)
Scalability	Low (manual, lab-intensive)	High (automated, rapid)
Key Limitation	Labour-intensive, static score	"Black box" complexity
Interpretability	Low (complex weightings)	High (with XAI tools like SHAP)

Results and Discussion

1. Predictive accuracy of ML/DL models

Recent studies confirm that ML models can predict soil quality with remarkable accuracy, often superseding traditional statistical methods. El Behairy *et al*. (2024) demonstrated this by using an ANN model to predict SQI from 16 soil features. The model achieved an outstanding coefficient of determination (R^2) of 0.97 for training and 0.98 for testing, indicating a near-perfect ability to generalize its learnings. Sumathi *et al*. (2023) employed a Deep Neural Network Regression (DNNR) model for soil quality classification and reported a high accuracy of 96.7%.

Ensemble models, which combine multiple algorithms, have proven particularly robust. Sadasivan *et al*. (2025) found that a Random Forest classifier achieved 97.73% accuracy for soil quality classification, outperforming both XGBoost and Support Vector Machine (SVM) models. In a separate study, Jameel and Chowdhary (2025) also found that ensemble models (XGBoost and a Stacked Ensemble) achieved over 95% classification accuracy, which was superior to individual baseline models.

These models are also moving beyond traditional chemical and physical inputs. Negiş *et al*. (2025) successfully used an ANN to predict soil quality from a simple, observable feature: soil colour. The model achieved a high R^2 of 0.70, by using CIELAB colour values (L*, a*, b*) as inputs, demonstrating the potential for rapid, low-cost assessment. The integration of geospatial data is enhancing predictive power. The Spatial-Aware Neural Network (SANN) used by Jameel and Chowdhary (2025) improved performance by up to 10% in areas with sparse soil sampling, proving its utility for regional-scale mapping.

2. Key Indicators and Model Interpretability

A primary criticism of complex models like ANNs is their "black box" nature; their decision-making process is not inherently transparent, which can be a significant barrier to trust and adoption. The challenge is now being solved by Explainable AI (XAI) tools, such as SHAP (SHapley Additive exPlanations).

SHAP analysis runs on top of the trained ML model and quantifies the impact of each feature on the final prediction, allowing researchers to identify which soil properties were most influential, effectively opening the "black box." Jameel and Chowdhary (2025) used SHAP to clearly identify Nitrogen, pH, and Organic Carbon as the three most important features in their soil quality model. The finding aligns with conventional soil science principles and validates the model's logic. Studies on traditional SQI development using PCA have also identified soil organic carbon and related biological indicators (like microbial biomass and enzyme activity) and soil acidity (pH and exchangeable acidity) as the most critical components for differentiating soil quality across different land uses (De *et al*., 2022; Simfukwe *et al*., 2021). The convergence of both traditional PCA and modern XAI on the same key indicators (organic matter, nutrients, and acidity) provides strong confidence that these predictive models are learning and prioritizing the correct scientific relationships, making the model's output transparent, trustworthy, and, most importantly, actionable.

Conclusion

The assessment of soil quality is rapidly evolving from slow and costly laboratory analysis to fast, scalable, and highly accurate predictive. Artificial intelligence and machine learning models, including ANNs, ensemble methods, and advanced SANNs, are consistently demonstrating their ability to predict soil quality with a high degree of accuracy.The future of soil management lies in combining these powerful predictive engines with Explainable AI (XAI) tools like SHAP. This synergy creates systems that are not only accurate but also transparent, interpretable, and trustworthy. These tools will be essential for supporting real-time, data-driven decisions in precision agriculture, helping to enhance productivity and ensure the sustainable management of our vital soil resources.

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SOIL HEALTH: THE SILENT FOUNDATION OF FOOD SECURITY

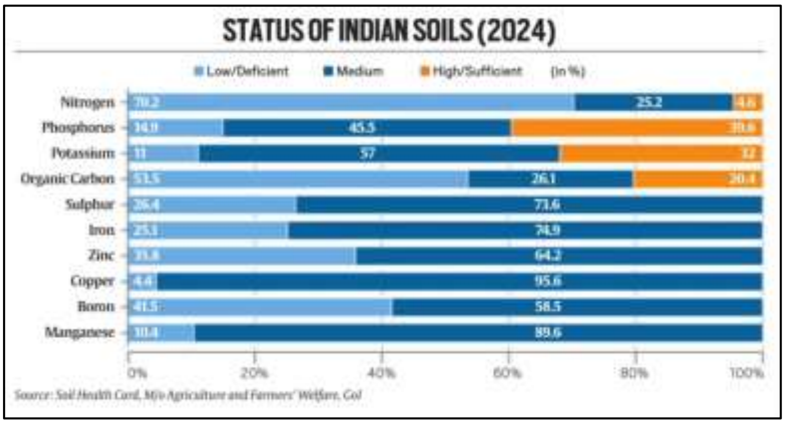
Introduction:

Soil is the backbone of agriculture: A living, dynamic mixture of organic matter, minerals, water, air and microorganisms that work together to support plant growth. This seemingly simple yet incredibly complex system sustains the food we eat every day. It is reported that nearly 33 per cent of global soils are degraded, with projections suggesting that over 90 per cent could be affected by 2050 in the absence of sustainable practices (FAO 2015a; 2020). This alarming situation threatens future agricultural productivity and highlights the necessity of prioritizing soil health.

Healthy soil forms the foundation of a vibrant and resilient ecosystem. It serves as a natural filter, cleansing water as it moves through the soil layers, thereby removing impurities and keeping groundwater safe for drinking and irrigation. In addition, soil functions as a crucial carbon sink, capturing atmospheric carbon dioxide and helping to reduce the impacts of climate change. A well-balanced soil ecosystem nurtures a rich diversity of plants and animals, sustaining biodiversity and ensuring long-term ecological stability.

Soil Health:

According to the USDA Natural Resources Conservation Service (NRCS), "Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans." The Food and Agriculture Organization (FAO, 2015) defines soil health as "The capacity of soil to function as a living system, with ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and promote plant and animal health."



Key Indicators of Soil Health

Soil health is commonly assessed through a set of measurable indicators, including:

- **Soil Organic Matter (SOM):** Enhances fertility, structure and water-holding capacity.
- **Soil Structure and Aggregation:** Influences aeration, root penetration and erosion resistance.
- **Microbial Biomass and Diversity:** Represents biological activity, nutrient cycling and resilience to stress.
- **Soil pH and Nutrient Availability:** Affect nutrient uptake efficiency and microbial functions.
- **Cation Exchange Capacity (CEC):** Reflects soil's ability to retain and supply nutrients.
- **Bulk Density and Porosity:** Determine root growth potential and soil aeration.
- **Water-Holding Capacity and Infiltration Rate:** Influence drought tolerance and water use efficiency.
- **Soil Respiration and Enzyme Activities:** Indicate microbial activity and organic matter turnover.

The recent assessment of soil health in India (2024) reveals significant nutrient imbalances across the country. A major concern is nitrogen deficiency, observed in about 70.2 per cent of soils, while phosphorus and potassium are low in 14.9 and 11 per cent of soils, respectively. Organic carbon, a key indicator of soil fertility, is deficient in over half of the soils (53.5%), reflecting declining soil organic matter. On the other hand, micronutrients such as sulphur, iron, zinc and manganese are largely present at medium levels, whereas copper is mostly sufficient in nearly all soils.

Micronutrient Deficiencies and Human Health

Soil degradation will directly affect human nutrition along with crop growth. Soils deficient in key micronutrients like zinc, iron, boron and sulphur produce nutrient-poor crops, leading to hidden hunger. For example:

- Zinc deficiency in cereals is linked to childhood stunting, impaired cognitive development and reduced immunity.
- Iron-deficient soils contribute to anemia, particularly in populations relying on plant-based diets.

This scenario highlights the urgent need for region-specific soil fertility management, balanced nutrient application and adoption of organic and sustainable soil health practices to ensure long-term productivity and food security.

India has achieved self-sufficiency in food production, reaching 305.44 million tons in 2020–21. However, this success relies heavily on resource-intensive, cereal-dominated agriculture, which has led to soil degradation, nutrient depletion, and regional imbalances (FAO, 2024). The gap between food availability and equitable distribution persists, contributing to widespread malnutrition, the leading cause of poor health globally. India continues to have the largest number of undernourished people, ranking 111th out of 125 countries in the 2023 Global Hunger Index, highlighting the urgent need for sustainable soil

Approaches for Soil Health Management:

- **Soil Testing & Nutrient Management**
  Regular soil testing helps to identify nutrient deficiencies and imbalances. Using Soil Health Cards, farmers can apply fertilizers in precise manner, ensuring to get the required nutrients for crops and avoiding overuse of chemical inputs. This improves crop productivity and prevents soil degradation.
- **Organic Inputs & Biofertilisers**
  Incorporating organic matter such as compost, farmyard manure, green manure and biofertilizers enriches soil with

essential nutrients and beneficial microbes. These inputs improve soil structure, increase water-holding capacity and reduce dependency on chemical fertilizers, leading to sustainable and ecofriendly soil fertility.

- **Crop Diversification & Rotation**

  Alternating crops, especially including legumes as a part of cropping system, helps to replenish nitrogen and other essential nutrients naturally. Crop rotation also breaks pest and disease cycles, reduces soil fatigue and maintains long-term soil productivity.

- **Agroforestry & Mulching**

  Integrating trees and shrubs in farmland (agroforestry) prevents soil erosion, retains moisture and contributes organic matter to the soil. Mulching with crop residues or cover crops protects the soil surface from erosion, conserves moisture and supports microbial activity.

- **Efficient Water & Soil Management**

  Adoption of water-efficient irrigation methods like drip or sprinkler systems reduces nutrient leaching and prevents salinization. Soil reclamation practices (lime for acidic soils, gypsum for saline soils) and conservation measures like minimum tillage, contour farming and terraces maintain soil structure and fertility.

The Government of India promotes soil health through multiple initiatives:

- **Soil Health Card Scheme**: Provides farmers with soil testing services and nutrient recommendations to improve soil fertility.
- **National Mission on Natural Farming (NMNF)**: Encourages bio-inputs, integrated farming, and regular soil monitoring.
- **Rashtriya Krishi Vikas Yojana (RKVY)**: Supports soil health and fertility, rainfed area development, organic farming, crop diversification, and agroforestry.
- **Paramparagat Krishi Vikas Yojana & MIDH**: Promote organic inputs, crop rotation, precision farming, and soil solarisation.
- **Agriculture Infrastructure Fund (AIF)**: Funds organic input production, bio-stimulants, and precision agriculture to maintain soil quality.
- **Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)**: Rejuvenates water systems, reduces runoff, and prevents soil erosion.
- **FPO Formation, PMFBY, and PM-KISAN**: Support organic/natural farming adoption and stable farm incomes, enabling sustainable soil management.

The Way Forward:

India must strengthen policy integration, expand soil testing and timely Soil Health Card issuance and promote organic farming, crop diversification, agroforestry and bio-input adoption to restore soil fertility. Building farmer capacity, supporting FPOs and incentivising precision irrigation will enhance productivity while conserving soil resources. By the end of 'Amrit Kaal' (2047), the CEEW roadmap envisions India's soil, our vital national resource will be restored to a regenerative state with rich biodiversity, ensuring nutritional security, contributing to climate change mitigation and supporting sustainable and resilient livelihoods.

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BIOFERTILIZER: IT'S TYPE AND USE IN SUSTAINING CROP PRODUCTION

Abstract

Biofertilizers are the latent cells which contains living strains of nitrogen fixing, phosphorus solubilizing and potassium solubilizing microorganisms. This is also called as microbial inoculants. It provides the nutrients either in symbiotic association or free living manner to crop plant. The insoluble nutrients can be mineralized by the application of biofertilizer. It can be applied to soil, seed and planting material by different method of application. The most common method is seed treatment with biofertilizer. This is a renewable source of nutrients, increase the nutrient holding capacity and water content of soil by increasing the crop yield by 10-40%. The effectiveness of biofertilizer depends on the soil temperature and climatic condition. So, utmost care should be taken for their application which will improve soil fertility and sustaining the crop yield.

Keywords: Microbial inoculant, living strain, biofertilizer, seed treatment.

Introduction:

Modern agriculture depends on use of fertilizer and pesticides to increase production and productivity of crop. But it badly affect the soil health and deteriorating its quality (Farnia and Hasanpoor, 2015). So, Biofertilizer will act as good alternative to provide plant nutrition. A biofertilizer is the substance which contains living strains of micro-organisms and promotes growth by supplying or make availability of primary nutrients to the host plant. It was applied to seeds, plant surfaces, or soil to colonize the rhizosphere or the interior of the plant for providing nutrients. This is also known as Microbial inoculants (Mitter *et al.*, 2021). It provides nutrients through the natural processes of fixing nitrogen, solubilizing phosphorus, and stimulating plant growth through the synthesis of growth-promoting substances (Chaudhary *et al.*, 2021). Biofertilizers are formulations that contain living or dormant cells of beneficial microorganisms such as nitrogen-fixing, phosphate-solubilizing, or cellulose-decomposing strains applied to seeds, soil, or compost. Their primary purpose is to enhance the soil's nutrient content and promote better plant growth. The microorganisms in biofertilizers build soil organic matter and restore the soil's natural nutrient cycle. It helps in growth of healthy plants and enhancing the sustainability of the soil. The use of synthetic fertilizers and pesticides can be reduced by their increased use in future. So, scientifically it is known as Plant Growth Promoting Rhizobacteria (PGPR). They help in build up soil micro flora & soil health. It also helpful for improving the soil fertility.

Types of Biofertilizer:

1. Bacterial: It is of 2 types

a.Symbiotic Nitrogen fixer Ex- Rhizobium sp.

b. Free living Nitrogen fixer Ex- Azotobacter, Azospirillum , Klebsiella etc.

2. Algal: Blue Green Algae (BGA) in association with Azolla to form *Anabaena azollae* complex which helps in providing nutrients.

Ex- Nostoc, Anabaena etc.

3. Phosphate Solubilising Bacteria: It solubilizes the insoluble form of phosphorus and provides the nutrients.

Ex- *Pseudomonas* sp., *Bacillus* sp.

4. Potasssium Solubilising Microorganism: Potassium solubilizing microorganisms (KSMs) are beneficial soil microbes capable of converting insoluble forms of potassium such as feldspar, mica, and illite into soluble, plant-available forms (K^+)**.**

Ex - *Bacillus mucilaginosus, Frateuria aurantia, Aspergillus niger, Aspergillus terreus* and *Penicillium spp.*

5. Fungal Biofertilizer: Vescicular Arbuscular Mycorrhizae (VAM) is also called as Arbuscular Mycorrhizae Fungi (AMF) is the association of fungus with roots of higher plants.

A.Bacterial biofertilizers:

- The living cells of bacteria used as biofertilizer.
- These microbes contain unique cell called as Nif gene.

The N fixing bacteria is working under two conditions i.e. Symbiotic & free living.

- The symbiotic bacteria make an association with crop plant by formation of root nodule.
- The free living bacteria fix atmospheric nitrogen without any association.

I. Symbiotic Nitrogen fixer:

Most important symbiotic nitrogen fixer is *Rhizobium* sp.

- Rhizobium lives in the root hair of legume by forming nodule.
- Plant root provide essential minerals & substances to microorganuism.
- There is the cross inoculation group for nodulating the legume plant by bacteria.
- The slow growing sp. is called Bradyrhizobium & fast growing sp. called Rhizobium sp.
- Rhizobium can fix upto 50-300 kg Nha^{-1}.

(Figure 1. Rhizobium and Legume Nodule formation)

Table 1. Cross inoculation group of Rhizobium groups:-

Rhizobium sp.	Crop
Rhizobium trifoli	Berseem
Rhizobium meliloti	Lucerne, Fenugreek
Rhizobium leguminocearum	Pea, Lentil, Groundnut
Rhizobium phaseoli	Bean
Rhizobium lupini	Lupinus, Ornithus
Rhizobium japonicum	Soybean

II. Free living Nitrogen fixer:

1. Azospirillum:

- It mainly present in cereal plant.
- It present in root cell as well as in surrounding plant.

- The nitrogen fixing capacity is 20-40 $kgha^{-1}$.
- This is also commercially exploited for nitrogen fixing.

2. Azotobacter:

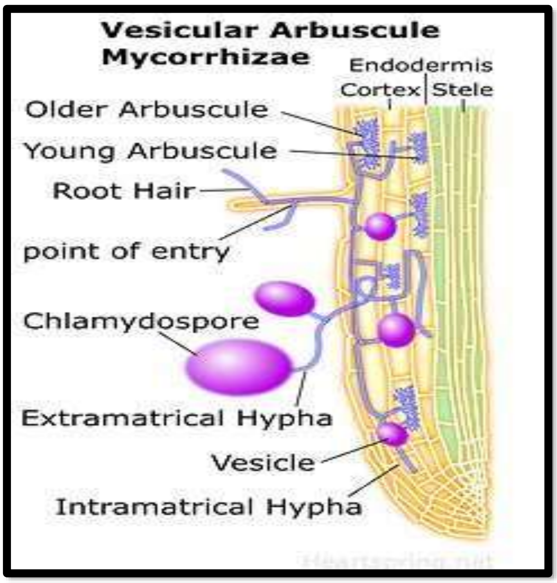
- Azotobacter is nitrogen fixing bacteria having free living nature and found in neutral & alkaline soil.
- It is commonly occuring in arable soil.
- Apart from fixing nitrogen it also synthesise growth promoting substances like auxin, gibberllines & vitamins.
- Many of the azotobacter exhibit fungicidal effect.
- Azotobactor mainly applied in rice, maize, cotton, sugarcane and pearl millet.
- It improve seed germination & plant growth.

B. Vesicular Arbuscular Mycorrhizae:

- The term "mycorrhiza'' means fungus root.
- The mycorrhiza is association between fungus & roots of higher plant.
- VAM is endotrophic mycorrhiza
- VAM helps in nutrient transfer particularly phosphorus, sulphur etc.
- It plays very important role in inducing plant growth.
- VAM colonize roots of 80% plants.
- VAM helps in storing soil moisture in the root zone of plants.
- It is having resistant against soil borne & root borne pathogen.
- It also mobilize other nutrients like Cu, Mn, Fe, K, Mg from soil to plant roots.
- They posses vesicle (sac like structure) for storing the nutrients & arbuscule for transfering them into root system.

Mechanism:

- The VAM form an association with plant root.
- It penetrate inside the root cortex & spreads around the root (Abd El-Lattief, 2016).
- It posses sac like structure called vesicles to store phosphorus as phospholipid.
- Arbuscule helps in providing oxygen and bringing the distant nutrients to the vesicle & root.



(Figure 2. VAM Mechanism)

C. Algal biofertilizer:

- This group of biofertlizer also called as cyanobacteria.
- It is also called as Blue green algae.
- There are 100 species of BGA which can fix nitrogen.
- Heterocyst is the specialized structure where BGA fix the nitrogen.
- BGA application mostly found in rice field.
- These are inhibited by chemical fertilizer.
- Inoculation of BGA increase the yield upto 10-14 %.
- They are easy to produce.

- These are very cheaply available.
- Beneficial for crops like vegetable, cotton & sugarcane.

Ex- Anabaena, Nostoc, Oscillatoria.

Table 2. Biofertilizer and their use in Various crop

Types of Biofertilizer	Contributions in Plant growth	Crops
Rhizobium sp.	Fix 40-200 Kg Nha^{-1}. Increase the yield by 10-30%.	Gram, Pea, Groundnut, Soybean, Berseem, Lucerne.
Azotobacter	Fixes 15-20 Kg $Nha^{-1}yr^{-1}$. Provides plant growth hormones like IAA, GA etc. Increase crop yield by 15-20%.	Sunflower, Sugarcane, Banana, Coconut & Plantation crop.
Azospirillum	Fixes 10-20 Kg Nha^{-1}. Increases root development.	Maize, Rice, Wheat & Finger millets
Azolla	Use as green manure. It can fix 30-40 Kg Nha^{-1} (Rahimi *et al*., 2014).	Rice
Blue Green Algae	It can fixe 20-30 Kg Nha^{-1} in lowland rice.	Rice, Banana
Phosphate Solubilising Microorganism (PSM)	It solubilizes near about 50-60% of fixed P in the soil and increase in yield by 10-20%.	Millets, Oilseeds, Pulses & Vegetables.
Potassium Solubilising Microorganism (KSM)	It helps in mineralization of fixed K in soil.	Almost all crops.

D. Azolla:

- Azolla is water fern commonly found in pond, ditches.
- It is growing in rice crop as biofertilizer.
- The nitrogen fixing ability accomplished by symbotic relationship between azolla & BGA.
- In addition to nitrogen, it provides P, K, Zn to the crop.
- The growth of Azolla replicate within 5-7 days.
- It fix 20-30 kg Nha^{-1}.
- Increase crop yield upto 15-20 % in the rice crop.
- It can tolerate to heat & cold.
- Nitrogen fixation upto 4-5 %.

(Figure 3. Azolla)

Method of application:

Biofertilizer can be applied to seed, seedling and soil based on their requirement and activity of microorganism (Bhattacharjee and Dey, 2014). There are 3 methods for applying Biofertilizer.

1. Seed treatment
2. Root dipping
3. Soil application

1. Seed treatment:

- Seed treatment is most common process of applying biofertlizer.
- Seed treatment with Rhizobium, Azotobactor, Azospirillum and PSB.
- Important things that the seed should be coated first with Rhizobium then with PSM culture.

- This method provide maximum no. of population which is required for better result.
- 20 g of Rhizobium culture is required to treat 1 kg seed.
- 1 packet contains 200g Rhizobium culture.
- For small seeded pulse crop 500 g of Rhizobium culture is sufficient for 1 hactare area.
- For Ground nut, 1.5 kg of Rhizobium culture for 80-100 kg seeds for 1 hactare area is required.

2. Root dipping:

- This method is mostly employed for application of Azospirillum in paddy or vegetable seedling.
- A fixed quantity of biofertilizer (Azospirillum) mixed with 5-10 litres of water at one corner of the field then the seedlings are dipped in it and after half an hour the plants taken for sowing.

3. Soil application:

- Phosphorus Solubilising microorganism (PSM) are soil applied.
- In this method, 400-600 kg cow dung mixed with 2 kg of PSM along with ½ bag of rock phosphate.
- The mixture should be kept in shade for overnight & maintain the moisture upto 50%.
- The mixture can be used as soil application in rows during land levelling.
- In Azotobacter & Azospirillum, 2 kg of carrier based inoculum mixed with 25 kg FYM and 25 kg soil and broadcasted in the field uniformly before transplanting.

Precautions:

- Store biofertilizer in cool & dry place
- Use right combination of biofertilizer.
- Use the packets befoe expiry date to increase effectiveness.

*For seed treatment follow the rotation i.e. Fungicide-Insecticide-Rhizobium (FIR)

Advantage:

- This a renewable source of nutrients for soil.
- It can sustain soil health in long run.
- Increase crop yield upto 10-40%.
- Improve structure, water retention capacity and porosity of soil.
- There is no negative effect on soil and plant.
- It acts as solubilizing & mobilizing agent.
- This is eco friendly, non polluting & cost effective method.

Disadvantage:

- Biofertlizer require special care for effective use.
- It must be use before expiry date.
- The effectiveness depends soil temperature and other climatic condition.

Conclusion:

Biofertilizer is very effective in providing plant nutrition and increasing crop yield. It is much more beneficial in substituting the chemical fertilizer and pesticide. Proper care should taken for its formation and application in field at right dose and right time to increase the effectiveness. It is very cheap and cost effective sothat all groups of farmers can use it in long run. It also increase the soil physical and chemical properties which helps for sustaining crop growth.

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PEARL FARMING: NATURE'S HIDDEN GEM

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Abstract:

Although pearl farming is often ignored in discussions about agriculture, it is a sign of new and sustainable farming methods. This article talks about the new field of pearl farming, describing its unique qualities and the many positive effects it has on the environment and society. Pearl farming is a type of agriculture that goes beyond what most people think of when they think of farming. Instead of growing crops on land, it grows beautiful pearls in marine ecosystems. Pearl farming is a unique and valuable business because it combines gem creation with aquaculture. This is what makes it so abstract. Pearl farming also helps protect biodiversity by making marine environments better and giving a home to many different types of aquatic life. Pearl farming has good effects on many parts of society and the environment, in addition to being beautiful. Pearl farming helps rural areas by giving them more ways to make money, and it helps coastal towns by giving them more ways to make money. It also helps local businesses and sustainable development by giving people chances to start their own businesses. The beneficial effects of pearl cultivation are based on environmental sustainability.
Key words: Pearl, innovation, sustainability, socioeconomics, entrepreneurship

Introduction:

One of the most beautiful and timeless natural gems in the world is the pearl. Certain molluscs, like oysters and mussels, make them in their soft tissue. When a small irritant, like a grain of sand or a parasite, gets into the shell, the mollusc secretes layers of calcium carbonate around it. This is called nacre or mother-of-pearl. These layers build up over time to make a shiny pearl.The size, shape, colour, and shine of pearls depend on the type of mollusc and the place where they form. For thousands of years, people have loved pearls for their beauty and rarity. They have been important to many cultures and times in history. Many cultures around the world have used them to decorate jewellery, clothes, and other decorative items to show wealth, purity, and elegance.

Pearl Farming

Pearl farming, also called pearl cultivation or pearl culture, is the process of raising molluscs like oysters and mussels to make high-quality pearls. This practice started in ancient China and India and has grown into a huge global industry that produces pearls in many sizes, shapes, and colours over the course of thousands of years.

Molluscs are carefully cared for in modern pearl farms, both freshwater and saltwater, to make sure they grow and make pearls in the best way possible. The first step is to choose healthy molluscs that can make better pearls. Then, a small bead or piece of tissue is put into their soft tissue through a process called nucleation. This makes nacre, the shiny substance that makes a pearl, come out.

A pearl's quality depends on a number of things, such as the health of the mollusc, the quality of the nucleus, and the environment around it. Pearl farming is a long-term solution to the problem of collecting wild pearls. It helps protect natural ecosystems and creates jobs and economic growth in many coastal areas.

Technological improvements have made pearl farming much better, allowing for the production of pearls in a wider range of colours, shapes, and lustres, which has made them more appealing to people all over the world.

Evolution of Pearl Farming in India

India has a long history of making and using pearls. Ancient records and archaeological finds show how important they were to Indian culture. Traditional methods used natural oyster beds and simple ways to make pearls.

The modern era of Indian pearl farming began when scientists started using controlled nucleation and other scientific methods. These methods were based on techniques that were developed in Japan and changed to work in India.

Research institutions have been very important in moving the industry forward. The Central Institute of Freshwater Aquaculture (CIFA) in Bhubaneswar, Odisha, India, was set up in 1987 by the Indian Council of Agricultural Research (ICAR) and has been a major contributor. CIFA has greatly improved freshwater pearl farming and encouraged environmentally friendly aquaculture practices across the country through cutting-edge research, training, and technology.

People in the Malabar region call Kerala the "mussel fishery zone of India." In the early 1970s, the Central Marine Fisheries Research Institute in Kochi did studies and demonstration trials all over India as part of group farming efforts in Kerala. They came up with simple, eco-friendly ways to farm.

Grouping pearls according to their quality

There are three main groups that pearls can be put into, which are listed below.

Natural pearls

These pearls grow naturally in the environment when mussels swallow something that doesn't belong there. Natural pearls have a small core, or nucleus, surrounded by thicker crystalline pearl nacre. It is not very big and has an uneven shape. The roughness of the surface of a natural pearl comes from the edges of the aragonite crystals that cover it.

Pearl from the sea

Made by many different types of marine molluscs, like clams, pearl oysters, common edible oysters, gastropod snails, and scallops.

Pearl from freshwater

Saltwater cultured pearls are made in lakes and rivers by different kinds of freshwater molluscs.

Pearl from saltwater

Mostly made by three kinds of pearl oysters.

Freshwater Cultured Pearl: These pearls are made in freshwater lakes and rivers by marine clams and mussels.

Pearls from the East: Natural saltwater pearls from the Orient (which includes Asia and the Far East) are called "Oriental Pearls." People thought these pearls were the most beautiful of all pearls because they had the best shapes and sizes. They had a unique look that combined a deep shine with soft colours that could be seen through their translucent "skins." This feature is known as a pearl's "Orient."

Conclusion:

Pearl farming is a promising new way to farm that is both innovative and environmentally friendly. It shows how aquaculture and gem production can work together to help people and the environment. Pearl farms are good for the environment because they help marine biodiversity and stop habitat destruction, which shows that they care about the environment. From a socioeconomic point of view, they give coastal communities other ways to make money, encourage business ownership, and make local economies stronger. Pearls represent elegance and tradition in culture, and pearl farming keeps skills alive and encourages people from different cultures to work together. Pearl farming shows the way to a strong, responsible, and welcoming future in agriculture by using sustainable methods, caring for the environment, and giving people the tools they need to succeed. With more research, money, and cooperation, its full potential to improve lives, protect ecosystems, and inspire positive change can be reached.

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AGRITOURISM AND RURAL DEVELOPMENT

Introduction

Agriculture has been the backbone of human civilization for centuries, sustaining livelihoods, cultures, and economies. In a rapidly globalizing world where urbanization and industrialization dominate, rural communities often face neglect, poverty, and migration challenges. To revitalize rural life and preserve agricultural traditions, Agri-tourism has emerged as a bridge between farming and tourism. It is a form of sustainable tourism that allows urban dwellers to experience rural culture, agricultural activities, and natural beauty while simultaneously benefiting local communities. Agri-tourism not only promotes rural development but also enhances farmers' income, creates employment opportunities, and preserves cultural heritage.

This article explores the concept of Agri-tourism, its benefits, challenges, and role in promoting sustainable rural development, while highlighting its significance in the Indian context and globally.

Concept of Agri-Tourism

Agri-tourism can be defined as a type of tourism where visitors travel to rural areas and participate in agricultural activities, cultural traditions, and farm-based experiences. Unlike conventional tourism, which is often centered around cities, monuments, and beaches, Agri-tourism offers authentic experiences such as:

- Staying in farmhouses or village homes
- Participating in activities like harvesting, sowing, or cattle rearing Tasting organic and traditional foods
- Learning indigenous farming practices

Exploring rural handicrafts, folk arts, and cultural festivals

Agri-tourism is part of the larger framework of rural tourism and aligns with sustainable tourism principles by emphasizing community participation, environmental conservation, and socio-economic equity.

Importance of Agri-Tourism for Rural Development

1. Diversification of Farmers' Income

Agriculture in many countries, including India, faces challenges like low productivity, climate variability, and price fluctuations. Agri-tourism provides farmers with an additional, reliable source of income by utilizing their farms not just for cultivation but also as tourist attractions.

2. Employment Opportunities

Agri-tourism promotes local employment in guiding, food preparation, hospitality, handicrafts, and cultural performances. Youth who would otherwise migrate to urban areas for jobs can find meaningful work within their communities.

3. Promotion of Rural Culture and Heritage

Villages are reservoirs of traditional knowledge, crafts, music, and cuisine. Agri-tourism helps preserve these traditions by showcasing them to visitors and providing artisans with a market for their skills.

4. Strengthening Farmer-Consumer Relations

Urban consumers often remain disconnected from the realities of food production. Agri-tourism allows them to witness farming processes firsthand, thereby fostering appreciation for farmers and encouraging demand for organic and locally grown food.

5. Infrastructure Development

As Agri-tourism expands, rural areas benefit from improved roads, sanitation, electricity, and internet connectivity, which in turn enhances the quality of life.

6. Women Empowerment for local residents.

Women play a vital role in rural households and agriculture. Through agri-tourism, women can engage in home-stays, food processing, and handicrafts, thereby gaining financial independence and recognition.

Agri-Tourism in the Indian Context

India, with its vast agricultural base and diverse rural culture, holds immense potential for Agri-tourism. States such as Maharashtra, Kerala, Punjab, and Rajasthan have pioneered initiatives in this field.

Maharashtra: The Agri-Tourism Development Corporation (ATDC) has played a crucial role in training farmers and creating agri-tourism centers. Visitors are offered activities like bullock cart rides, crop cultivation, and traditional food experiences.

Kerala: Known as "God's Own Country," Kerala promotes farm tourism through spice plantations, paddy fields, and houseboat experiences, blending agriculture with eco-tourism.

Punjab: The state highlights its rich agricultural prosperity with mustard fields, tractor rides, and cultural festivals like Baisakhi.

Rajasthan: Desert farming, camel rides, and traditional crafts attract tourists from around the world.

Government initiatives such as Rural Tourism Schemes under the Ministry of Tourism, subsidies for farmers, and skill development programs have further boosted this sector.

Global Perspectives on Agri-Tourism

Agri-tourism is not limited to India; it is a growing phenomenon worldwide:

Italy: Known as the pioneer of Agri-tourism, Italy promotes vineyards, olive farms, and countryside stays that have become global tourist attractions.

United States: Farm stays, pumpkin festivals, and wine tourism are popular forms of Agri-tourism.

Japan: Rice planting and harvesting festivals attract international visitors while preserving age-old traditions.

African Nations: Safari-linked Agri-tourism and organic farming initiatives support rural economies.

The global trend reflects that Agri-tourism is not just about farm visits but about creating unique cultural and agricultural experiences.

Challenges of Agri-Tourism in Rural Development

While Agri-tourism has vast potential, several challenges hinder its growth:

Lack of Awareness: Many farmers remain unaware of how to integrate tourism with farming practices.

Infrastructure Deficiency: Poor rural roads, sanitation, and communication facilities discourage tourists.

Skill Gaps: Farmers often lack hospitality management skills and marketing expertise.

Seasonal Dependence: Agricultural activities are seasonal, limiting year-round tourist attraction.

Financial Constraints: Initial investment for setting up accommodations, marketing, and facilities is often unaffordable for small farmers.

Environmental Concerns: Unregulated tourism can lead to overuse of resources and degradation of ecosystems.

Strategies to Promote Agri-Tourism for Rural Development

To overcome these challenges and maximize benefits, the following strategies can be adopted:

Government Support: Provide subsidies, loans, and policy incentives for farmers engaging in agri-tourism.

Capacity Building: Training programs in hospitality, marketing, and language skills for rural youth and farmers.

Public-Private Partnerships: Collaboration between government, NGOs, and private investors for infrastructure development.

Digital Promotion: Use of social media and online platforms to reach domestic and international tourists.

Eco-Friendly Practices: Adoption of sustainable practices like organic farming, renewable energy, and waste management.

Community Participation: Ensuring that local communities are directly involved in planning and benefiting from agri-tourism projects.

Case Studies

1. Parashar Agri-Tourism, Maharashtra

Founded under the guidance of ATDC, this initiative allows visitors to experience traditional farming, bullock cart rides, and folk dances. It has not only increased farmers' incomes but also created awareness about rural lifestyles.

2. Spice Plantation Tours, Kerala

Tourists experience spice cultivation, traditional cuisine, and ayurvedic wellness. This has boosted both the tourism sector and spice exports from the region.

3. Tuscany, Italy

The integration of vineyards, olive farms, and rural homestays has transformed Tuscany into one of the world's leading agri-tourism destinations, contributing significantly to the local economy.

Role of Agri-Tourism in Sustainable Development

Agri-tourism directly contributes to the United Nations Sustainable Development Goals (SDGs):

SDG 1 (No Poverty): By increasing rural incomes.

SDG 2 (Zero Hunger): Promoting sustainable agriculture and local food systems.

SDG 8 (Decent Work and Economic Growth): Creating rural employment.

SDG 11 (Sustainable Cities and Communities): Strengthening rural-urban linkage.

SDG 15 (Life on Land): Encouraging eco-friendly farming practices.

Thus, agri-tourism is not merely a leisure activity but a tool for achieving global sustainability.

CONCLUSION

Agri-tourism represents the convergence of agriculture, culture, and tourism with immense potential to transform rural landscapes. It provides farmers with income diversification, empowers women, generates employment, and preserves traditions. At the same time, it offers urban populations a chance to reconnect with nature and appreciate the rural way of life.

However, challenges such as lack of infrastructure, awareness, and skill gaps need to be systematically addressed through government policies, training programs, and community participation. With the right strategies, agri-tourism can play a decisive role in ensuring rural prosperity, food security, and cultural preservation.

In an era marked by rapid urbanization and technological change, agri-tourism reminds us of our roots and the indispensable role of farmers. It is not just a tourism activity but a socio-economic movement capable of redefining the future of rural development.

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Agri-voltaic Farming: A sustainable approach for climate –smart Agriculture

INTRODUCTION

The fast pace of climate change and the growing number of people on Earth are two of the biggest problems that people face today. Agriculture, which feeds almost half of the world's people, is very sensitive to changes in the weather. In India, where almost 47% of the workforce works in agriculture, crops have been hurt by repeated droughts, unpredictable monsoons, and soil degradation. This has made food security worse. India's reliance on fossil fuels for energy production has also led to a lot of greenhouse gas (GHG) emissions, making it the third biggest emitter in the world. To fight this, the country has promised to reach net-zero emissions by 2070, which is in line with global climate goals. Agrivoltaics Farming, which combines photovoltaic (PV) systems with farming, is one promising solution that can help with both agricultural and energy problems at the same time. This method lets the same piece of land be used for both growing food and making renewable energy, which is a model of sustainability and resilience that works together.

The concept and Evolution of Agrivoltaics

The concept of Agrivoltaics (APV) or solar sharing, was introduced in 1981 by Adolf Goetzberger and Armin Zastrow in Germany. Their idea was simple yet revolutionary – to elevate solar panels above farmland to allow simultaneous solar energy production and crop cultivation. The key design principle of agrivoltaics is to optimize light distribution: solar panels capture part of the sunlight for energy, while the remaining light passes through or around panels to support photosynthesis in crops below. Modern agrivoltaics systems use elevated or adjustable solar structures that maintain appropriate spacing and tilt to balance shade and light availability.

Over the decade, agrivoltaics evolved through technological innovations such as:

. Transparent or bifacial panels that transmit diffused light,

. Adjustable tracking systems that optimize sun exposure, and

. Thin-film and polymer coating technologies that separate light wavelength beneficial for both crops.

Agrivoltaics optimizes land use by integrating solar panels with crops. The idea of agrophotovoltaics (APV) was initially conceived by Goetzberger and Zastrow in 1982 to modify solar power installations to allow simultaneous crop cultivation in the same area (13). For the technology, solar collectors were elevated 2 m above ground level and gaps were increased in the gaps between them to prevent excessive crop shading. These systems would require only one-third of the incoming solar radiation (14). It took approximately 30 years for this concept to be referred to as agro photovoltaic, agro PV, agri voltaic, or solar sharing. By generating both solar energy and agricultural products in a single location, it is possible to share light, enhance freshness and decrease moisture loss. The integration of solar technology with agriculture began in 1975 with the development of the first photovoltaic water pump.

Global Status of agrivoltaics

Agrivoltaic (AV) system categorized under agricultural 5.0 present a potential solution to the meet the growing needs of food and energy. These systems utilize power resources to support agricultural production, encompassing facility gardening, breeding and specialized pastoral structures thereby establishing a novel production model that integrates farming, power generation and agricultural activities (16). Research on solar energy applications in agriculture commenced as early as the 1960s in countries such as Britain, France, India, Portugal and the United States. The emergence photovoltaic technology gradually drew attention toward agrivoltaic applications The introduction of the first photovoltaic water pump in 1975 marked the inception of integrating photovoltaic technology with agriculture. However, this concept remained largely unexplored until 2004 when Akira Nagashima constructed the first system in Japan designating it as “solar sharing” (18). Subsequently AVS proliferated across Europe, Asia and the United States, ranging from small-scale family farming operations to extensive installations exceeding 700 MW in China, offering diverse benefits to farmers globally. China initiated large-scale agrivoltaic systems in 2014 and continues to maintain global leadership in installed capacity (19). France became the first European nation to support agrivoltaics, implementing regular tenders in 2017 systematically. By 2021 agrivoltaics had evolved into a market ready technology with a global installed capacity surpassing 14 GWp (20).

The role of agrivoltaics in advancing climate-smart agriculture

Agrivoltaic systems as emerged as an innovative and sustainable technology in response to escalating climate change, dwindling resources and increasing energy needs. These systems involve installing photovoltaic (PV) panels on agricultural land, enabling concurrent solar energy production and crop cultivation. Agrivoltaics systems optimize land utilization by combining energy generation and agriculture on a single plot. This dual-purpose approach mitigates the necessity for additional land conversion and attenuates the environmental impact. Some of the points highlighting the importance of the Agrivoltaics systems are listed below. 1. The shade provided by solar panels can reduce soil and water evaporation, resulting in more efficient water utilization in agriculture. This is particularly advantageous in arid and semi-arid regions with scarce water resources. By producing renewable energy, agrivoltaics systems decrease dependence on fossil fuels and reduce greenhouse gas emissions. This contributes to mitigating climate change and its effects on agriculture and ecosystems. The vegetation growing beneath and around solar panels can enhance carbon sequestration in soil and biomass, further reducing atmospheric CO2 levels. Solar panels can assist in minimizing soil erosion by shielding the soil surface from wind and water. This helps to preserve the soil structure and prevents the loss of valuable topsoil. Agrivoltaic systems can establish microhabitats that support the local flora and fauna. The solar panels and associated infrastructure can provide shelter and resources for various species. Enhanced soil health and decreased evaporation can lead to reduced need for chemical inputs such as pesticides and fertilizers. This can mitigate the environmental impact of agricultural practices and diminish the risk of runoff pollution. 7.The shading effect of solar panels can help crops withstand extreme weather conditions, such as heat waves and intense solar radiation, by moderating temperature extremes. This can enhance the resilience of agricultural systems to climate variability and severe weather events.

Impact of solar panel shading in agrivoltaic systems

Agrivoltaic systems contribute directly and indirectly to reducing greenhouse gas (GHG) emissions, primarily through the shading effects of solar panels. Agrivoltaic systems, which involve partially shading or covering the soil with photovoltaic (PV) modules, help to retain soil moisture and enhance its water-holding capacity. By reducing soil temperatures, these systems contribute to creating a more favorable environment for plant growth. Cooler soil temperatures help stabilize microbial processes, leading to a reduction in nitrous oxide (N_2O) emissions. Large-scale PV power generation is essential for mitigating climate change and agrivoltaics is emerging as a sustainable alternative energy source. It optimizes multifunctional land use by supporting both electricity generation and agricultural activities simultaneously. Additionally, the partial shade provided by agrivoltaic systems has been shown to benefit crop water balance and reduce evapotranspiration. The shading effects also support a broader range of plant and animal species, while cultivation practices under agrivoltaic systems further enhance soil quality.

Protection against heat and water loss, and increase in crop yields

As mentioned earlier, agrivoltaics can allow for the cultivation of crops by protecting them from heat stress and water loss. The shading the PV panels provide improves the microclimate beneath the solar panels and lowers the temperature on the ground, boosting agricultural productivity. A project in Algeria, for instance, has shown that agrivoltaics can lead to considerably higher yields, as well as size of the crops. Additionally, regions that have become infertile or that face progressive soil degradation due to extreme heat and drought can be restored with the help of agrivoltaics, while the favorable growing conditions also allow for a wider variety of higher-value crops to be cultivated, all whilst enhancing food security. The shading from the PV panels also lowers water demand by reducing water loss through evaporation. Meanwhile, agrivoltaic systems also allow for rainwater harvesting – this is particularly beneficial in dry and hot regions, where access to water is already limited.

New sources of income and jobs

The dual use of land for food and power production can also lead to a double income for farmers. The increased variety of crops already mentioned, as well as a potential income from the panels (e.g. through feed-in tariffs for surplus energy), can boost and diversify farmer incomes. Simultaneously, the installation, maintenance and operation of the PV modules also create jobs – even in structurally weak regions or in disadvantaged rural areas.

Conclusion

Accordingly, the advantages of agrivoltaics are enormous on the African continent, and thanks to high solar radiation, they might even be greater than in Europe. Political incentives and funding programmes that support the development of agrivoltaics could be a major lever to realize the multiple benefits the technology has. While agrivoltaics is still in the early stages on the African continent, the transfer of know-how and policy programmes, such as the Water-Energy-Food-Ecosystems Nexus, an approach focusing on integrated policy solutions that align water, energy and agriculture for mutual benefit, have the capability to improve food and energy security, all whilst benefiting the climate and the local population.

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BIOFERTILIZERS AND THEIR FUTURE

Summary:

Biofertilizers are natural fertilisers. These fertilisers have helpful microorganisms that help plants grow by making the soil more fertile and giving them the nutrients they need. They are good for the environment, promote farming that lasts, and save money. In the process of nitrogen fixation, nutrient absorption, and disease control, various types of biofertilizers, such as Rhizobium, Azotobacter, Azospirillum, and Mycorrhizae, play important roles. Even though they take a long time to work and need certain conditions to work, they are a great way to keep soil healthy and boost crop production because of the long-term benefits they offer. Organic and environmentally friendly farming will use biofertilizers in the future.

Introduction:

The term "biofertilizer" refers to natural products that contain living microorganisms that increase the amount of nutrients in the soil, thereby facilitating the growth of plants. Chemical fertilisers, on the other hand, are bad for the environment and can hurt the soil's ability to grow plants. They make the soil healthier, promote organic farming, and cut down on the use of chemicals. As people learn more about how to keep soil healthy, biofertilizers are becoming a big part of sustainable farming and the future of farming.

Features of Biofertilizers:

- Made of beneficial microorganisms like bacteria, fungi, and algae.
- Improve soil fertility and nutrient availability.
- Help recycle nutrients naturally in the soil.
- Safe for the environment and support organic farming

Different Types of Biofertilizers:

- Azospirillum: This type is used for non-leguminous crops like maize, rice, and wheat. It also helps in nitrogen fixation and promotes root development.
- Azotobacter: It is a free-living nitrogen-fixing bacteria used for crops like cotton, vegetables, and cereals.
- Blue-Green Algae (Cyanobacteria): These are used mostly in paddy fields as they add nitrogen naturally to the soil.

- Phosphate Solubilizing Microorganisms (PSM): These help to convert unavailable forms of phosphorus into a form that plants can easily absorb.
- Mycorrhiza: It is a fungus that forms a relationship with plant roots and helps plants absorb water and nutrients more efficiently.

Benefits of Using Biofertilizers:

Biofertilizers, which are made of living microorganisms and are good for the environment, can help the soil become more fertile and plants grow better. They work as a cheap substitute for chemical fertilisers and help keep the soil and water cleaner. They give plants the nutrients they need, help crops grow, and support farming that is good for the environment. Biofertilizers also make the soil healthier by encouraging the growth of helpful microbes and adding more organic matter.

Disadvantages of Biofertilizers:

Biofertilizers work slowly as the microorganisms take time to grow and multiply. They are often crop-specific and may not perform well under extreme soil or weather conditions. Their shelf life is short and they need proper storage. Sometimes, introduced microbes compete with native ones, reducing their effectiveness. In addition, production and quality control can be challenging, making them less accessible to some farmers.

Types of Microbes Used as Biofertilizers:

Several types of microorganisms are used as biofertilizers. **Rhizobium** lives in legume roots and fixes nitrogen to improve soil fertility. **Azotobacter** and **Azospirillum** also fix nitrogen and promote root growth in non-legume crops. **Mycorrhizae** are fungi that help plants absorb nutrients and water more efficiently. **Bacillus subtilis** and **Pseudomonas fluorescens** protect plants from diseases and support healthy growth. **Trichoderma** is a fungus that controls soil-borne diseases and enhances plant growth

Conclusion:

Biofertilizers are a natural and environmentally friendly method of enhancing the fertility of the soil and the growth of crops. They lessen the requirement for the use of chemical fertilisers, promote organic and sustainable farming practices, and contribute to the preservation of healthy soil. Because of the numerous advantages they offer, biofertilizers are poised to play a significant part in the agricultural industry of the future.

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ROLE OF BIO-PESTICIDES AND BIOFERTILIZER IN SUSTAINABLE AGRICULTURE WORLD

Summary

Bio-pesticides and bio-fertilizers are leading the way in the global shift towards sustainable agriculture. These natural inputs that come from living things are a necessary, eco-friendly alternative to synthetic chemicals. They promise a future of strong farming, healthier soils, and safer food. Biological farming is the way of the future. As the world deals with the environmental and health costs of traditional, chemical-heavy farming, bio-pesticides and bio-fertilizers are becoming the most important tools for creating a truly sustainable food system. These natural, eco-friendly inputs come from beneficial microorganisms, plant extracts, and minerals. They are a great way to get high yields without hurting the health of the planet or its people. Using bio-pesticides and bio-fertilizers together is the key to a more sustainable, environmentally friendly, and cost-effective farming world. By working in harmony with natural ecological cycles, these bio-inputs are not just alternatives; they are fundamental to achieving global food security, mitigating climate change (by promoting healthy soil, a carbon sink), and ensuring a healthier planet for generations to come.

Introduction

The world's food system is at a turning point. The Green Revolution depended a lot on synthetic chemical fertilisers and pesticides for decades to get the most out of crops. This method has worked to boost production, but it has also had a big impact on the environment and people's health. It has led to less fertile soil, polluted water, loss of biodiversity, and worries about chemical residues in food.

There is a "Quiet Revolution" going on right now, and it is based on biological solutions that work with nature instead of against it. Bio-pesticides and bio-fertilizers are the main things that farmers use these days. These are natural, eco-friendly inputs that come from living things like helpful microbes and plants.

These bio-inputs are more than just options; they are what makes a truly sustainable agriculture world possible. They bring ecosystems back into balance, improve the health of the soil, and give farmers a cheap way to grow safer, better food. To make sure that the world's resources are safe for future generations and that the growing population has enough food, we need to switch to these natural tools.

The core of sustainability:

There is a very important change happening in the world's agriculture. The industrial farming models of the past increased production but made people very dependent on synthetic chemicals. Using these things too much has really hurt the health of our soils. Made our water dirty and made the weather change. The good news is that both science and nature are coming up with a solution: a smart mix of bio-pesticides and bio-fertilizers. These "bio-inputs" are changing the way we farm in a big way, increasing yields and profits through ecological life.

Bio-fertilizers: the soil's friend

Bio-fertilizers are the living formulations of beneficial microorganisms that applied to seed, soil, or plants, enhance fertility and promote growth. Their role is to facilitate crucial natural processes that synthetic chemicals disrupt, essentially restoring the soil's innate productivity and soil health.

Bio-pesticides:

Unlike broad-spectrum chemicals that kill everything they touch, bio-pesticides are often **target-specific**. For instance, a microbial bio-pesticide like *Bacillus thuringiensis (Bt)* targets only certain insect larvae, leaving beneficial insects, pollinators, and natural predators unharmed. This preservation of the beneficial strengthens the ecosystem's own pest controls.

Bio-pesticides decompose quickly after use, leaving minimal to zero toxic residue on crops, soil, or water. This is a crucial factor for ensuring the consumer's safety and meeting increasingly the strict global food safety standards.

Their diverse and often complex modes of action make it significantly harder for pests to develop resistance, a perpetual problem with continuous use of single-chemical synthetics. Integrating bio-pesticides into an Integrated Pest Management (IPM) programs that ensures the long-term effectiveness of pest controlling in agriculture.

Easily understandable points and description for both Bio and Chemical (Fertilizers and pesticides):

Bio-fertilizers

Bio-fertilizers are natural fertilizers that contain living microorganism, which helps in increasing the supply or availability of essential nutrients to plants. Unlike chemical fertilizers, they are eco-friendly and improve soil fertility in a sustainable way.

Key features

- Eco-friendly and non-toxic.
- Reduce dependency on chemical fertilizers.
- Improve soil health and fertility.
- Cost-effective and sustainable in the long run.

Examples of Bio-fertilizers

- Rhizobium (for legumes)
- Azospirillum (for cereals)
- Azotobacter (for non-legumes)
- Blue Green Algea (BGA)
- Phosphate-Solubilizing Bacteria (PSB)
- Micorrhizal fungi

Applications

- Seed treatment: seeds are coated with bio-fertilizers before sowing.
- Soil applications: Mixed with compost or soil and applied.
- Root dipping: seedlings are dipped in bio-fertilizer slurry before transplantation.

Discussion

The correlation study clarified the complex interrelationships between the various aspects of sustainable agriculture. Studies that demonstrate biopesticides may have the ability to lower

Bio-fertilizers vs Chemical fertilizers

- **Bio-fertilizer:** living Microbes, fix N,solubalize P, eco-friendly.
- **Chemical fertilizers:** man-made, supply NPK directly, fast but harm soil.
- **Bio** →improves the soil. Fertility;

Chemical →degrade soil with long use.

- **Bio** →cheap & sustainable;

Chemical → costly & polluting.

Bio-pesticides vs Chemical pesticides

- **Bio-pesticides:** natural origin (Bt, neem, fungi, viruses), eco-safe.
- **Chemical pesticides:** synthetic (DDT, malathion), toxic & polluting.
- **Bio** →specific to pests, safe for humans;

Chemical →kill pests fast but also harm beneficial organisms.

- **Bio** →leave no residues;

Chemical →residues accumulate in soil, water, food.

- **Bio = Natural, Eco-friendly, Sustainable.**
- **Chemical = Artificial, Quick, Harmful long-terms.**

The Bio Advantage vs. The Chemical Defect:

Switching to bio-inputs like bio-pesticides and bio-fertilizers has a clear range of benefits that are the opposite of the problems with chemical inputs. Bio-fertilizers improve the health of the soil by naturally fixing nutrients, increasing microbial biodiversity, and making the soil structure more stable. They also lower the cost of fertilisers. On the other hand, chemical fertilisers can deplete the soil, raise salinity, and cause a lot of water pollution from nutrient runoff. Bio-pesticides are a targeted, residue-free way to protect crops. They kill only the pests that are harmful to plants and animals, while keeping beneficial insects like pollinators safe. This makes food safer and the ecosystem healthier. Synthetic chemical pesticides, on the other hand, are usually broad-spectrum, killing important non-target organisms, leaving toxic residues on food, and speeding up the development of pest resistance, which means that stronger, more harmful chemicals must be used over time. The biological approach thus promotes a virtuous cycle of sustainability, profitability, and public health, supplanting the unsustainable cycle of dependency and environmental degradation caused by chemical inputs. Switching to bio-inputs (bio-pesticides and bio-fertilizers) has a clear range of benefits that are the opposite of the problems with their chemical counterparts. Bio-fertilizers improve the health of the soil by naturally fixing nutrients and increasing the diversity of microbes. This makes the soil more stable and lowers the cost of fertilisers. On the other hand, chemical fertilisers can deplete the soil, raise its salinity, and pollute the water with nutrients that run off.

Conclusion

The transition from the chemical-dependent farming to a biological-based system is more than technological upgrade; it is a **paradigm shift** that places ecological health at the center of food production. The combined, complementary power of bio-pesticides and bio-fertilizers offers a compelling vision for a Sustainable Agriculture World—one that is productive, profitable and planet-friendly.

We have moved past the era of where high yield inherently meant high environmental costs. Bio-fertilizers are now recognized as the architects of enduring soil health, ensuring that our most valuable resource remains fertile and vibrant for generations. By naturally fixing nitrogen, mobilizing locked-up nutrients, and enhancing the soil's structure, they are the key to building resilient farms that can withstand the challenges of a changing climate. Simultaneously, bio-pesticides represent a mature form of crop protection, offering surgical precision in pest control without the detrimental side-effects of broad-spectrum toxins. They safeguard the crucial biodiversity of the agricultural ecosystem, protecting pollinators and beneficial insects that are essential for natural balance and also for the highest yields.

While challenges remain—including improving the shelf life, consistency, and widespread availability of bio-products—the trajectory is undeniable. Policy support, farmer's education, and continued scientific innovation are rapidly addressing these limitations.

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MOLECULAR FARMING FOR IMMUNIZATION: CURRENT ADVANCES AND FUTURE PROSPECTS IN PLANT-PRODUCED VACCINES

Abstract

Plants are used as bioreactors in molecular farming to make vaccines, therapeutic proteins, and enzymes in a way that is both environmentally friendly and cost-effective. This approach offers high scalability, safety, and low contamination risk. Improvements in gene editing, temporary expression, and nanoparticle delivery have made it more effective. Medicago's Covifenz COVID-19 vaccine is an example of how quickly it can respond. Edible vaccines are a good option for areas with few resources because they don't need to be kept cold. But there are still problems to solve, such as low protein yield, complicated purification, and regulatory issues. This review talks about how plant-based vaccines have come along, how they can be used, and how they could be used in the future to make immunisation around the world more affordable and accessible.

Introduction

Global health challenges like COVID-19, influenza, and malaria have exposed the limits of traditional vaccines, which are costly, slow to produce, and difficult to distribute, especially in low- and middle-income countries. Molecular farming, which uses plants as bioreactors, offers a sustainable and affordable alternative for vaccine production. Plants can produce therapeutic proteins and antigens safely, without risk of human pathogen contamination, and at large scales with lower costs. Techniques such as transient expression using Agrobacterium tumefaciens enable rapid vaccine production, as shown by Medicago's Covifenz, the first approved plant-based COVID-19 vaccine. Edible vaccines in crops like lettuce and tomatoes also promise easy delivery without cold storage needs. With advancements in genetic engineering and biotechnology, plant-based vaccines have the potential to revolutionize global immunization by providing accessible, efficient, and eco-friendly solutions.

2. Historical Perspective on Plant-Based Vaccines

The concept of using plants as biofactories for therapeutic proteins emerged in the early 1990s with advances in molecular biology and genetic engineering. Early research focused on producing simple recombinant proteins like antibodies and enzymes in crops such as tobacco and potato.

A major milestone came with the successful production of human growth hormone and hepatitis B surface antigen in transgenic plants, proving plants could produce functional vaccine components. This led to the idea of edible vaccines using crops like tomatoes and bananas for easy, low-cost immunization in developing regions.

The development of transient expression systems revolutionized molecular farming, allowing rapid and high-yield protein production without stable genetic modification. The use of Agrobacterium tumefaciens and plant viruses enabled fast vaccine development, demonstrated by Norwalk virus and influenza candidates. The most notable success was Medicago's Covifenz, a plant-derived COVID-19 vaccine using virus-like particles (VLPs), approved in 2022 by Health Canada.

Plant-based vaccines have also advanced in veterinary medicine, showing potential for diseases like Newcastle and porcine epidemic diarrhea. These milestones mark the evolution of molecular farming into a promising tool for sustainable, large-scale vaccine production.

3. Mechanisms of Molecular Farming

3.1. Plant Expression Systems

Plant expression systems are the foundation of molecular farming for producing recombinant proteins and vaccines. Two main approaches are used: transient expression and stable transformation.

Transient expression, often achieved through Agrobacterium tumefaciens–mediated agroinfiltration or viral vectors like Potato Virus X (PVX), enables rapid protein production within days. This system is efficient, cost-effective, and ideal for responding quickly to pandemics.

Stable transformation integrates the target gene permanently into the plant genome via nuclear or chloroplast transformation. Chloroplast transformation offers higher protein yields, genetic stability, and prevents gene escape through pollen. Though slower, it supports long-term and large-scale vaccine production.

3.2. Plant Hosts in Molecular Farming

Common plant hosts include tobacco, lettuce, tomato, and maize. Tobacco (Nicotiana benthamiana) is widely used for high-yield transient expression. Lettuce and tomato serve as models for edible vaccines, offering oral delivery without processing, while maize enables large-scale, stable production with natural encapsulation of proteins.

3.3. Comparison with Other Systems

Compared to microbial, fungal, and mammalian systems, plant-based expression offers human-like protein folding and glycosylation, lower production costs, and reduced contamination risks. Though protein yields are generally lower and expression slower, plants provide a safer, more sustainable, and scalable alternative for vaccine and therapeutic protein production.

4. Applications of Plant-Based Vaccines

4.1. Infectious Diseases

Molecular farming uses plants to produce vaccines and therapeutic proteins. Plants like Nicotiana benthamiana, lettuce, and maize are engineered to express vaccine antigens. This method is low-cost, scalable, and safer, with no risk of human pathogen contamination. A key example is the plant-based COVID-19 vaccine (Covifenz). Plant-made vaccines are being developed for influenza, hepatitis B, malaria, and cholera.

However, challenges include low yield, purification difficulty, and regulatory delays.

4.2. Edible Vaccines

Edible vaccines—produced in crops like bananas, tomatoes, and lettuce—allow oral immunization without cold storage, ideal for low Plant-based vaccines have shown strong potential against major infectious diseases like COVID-19, influenza, hepatitis B, and malaria. Medicago's Nicotiana benthamiana–derived Covifenz vaccine was a major success, producing virus-like particles (VLPs) mimicking the SARS-CoV-2 spike protein. Similar VLP-based vaccines for influenza and malaria have also shown high immunogenicity in trials. These vaccines are cost-effective, scalable, and safe, offering rapid production and reduced contamination risks compared to traditional methods. -resource settings. However, challenges include inconsistent antigen expression, dosage control, and protein stability during digestion. Techniques such as freeze-drying and encapsulation are being developed to improve stability and delivery.

4.3. Therapeutic Vaccines

Therapeutic plant-based vaccines aim to treat diseases like cancer, autoimmune disorders, and chronic infections. They express tumor-associated or viral antigens that stimulate targeted immune responses. Studies have shown promising results for cancers such as lymphoma and breast cancer, as well as chronic infections like HIV and tuberculosis.

4.4. Veterinary Applications

Plant-based vaccines are also valuable in animal health, preventing diseases such as Newcastle disease, rabies, and foot-and-mouth disease. They are safe, affordable, and suitable for mass production. By reducing zoonotic infections, they support the "One Health" approach linking human, animal, and environmental well-being.

5. Benefits of Plant-Based Vaccines

5.1. Cost-Effectiveness and Scalability

Plant-based vaccines are highly economical and scalable compared to traditional systems that rely on costly bioreactors. Plants like Nicotiana benthamiana and N. tabacum can be cultivated in fields or greenhouses, requiring minimal infrastructure and resources. Local cultivation reduces transportation costs and cold-chain dependence, while edible vaccines further cut costs by enabling oral delivery through food crops.

5.2. Rapid Response to Pandemics

Plants can be genetically modified quickly to produce new antigens, allowing rapid vaccine development during outbreaks. Unlike egg- or cell-based methods that take months, plant systems can generate vaccine candidates within weeks. Controlled indoor cultivation ensures consistent yields, biosafety, and year-round production, making them ideal for pandemic preparedness.

5.3. Safety and Low Contamination Risk

Because plants are not hosts for human pathogens, they eliminate the risk of contamination common in animal-based systems. They also avoid the use of animal-derived materials such as fetal bovine serum, reducing zoonotic risks and ethical concerns while ensuring cleaner production processes.

5.4. Environmental Sustainability

Plant-based production is energy-efficient and environmentally friendly. It consumes less water, produces minimal waste, and generates a smaller carbon footprint than conventional vaccine manufacturing. Localized production reduces transportation emissions, aligning with global sustainability goals.

Overall, plant-based vaccines combine affordability, safety, speed, and sustainability—making them a transformative solution for equitable and eco-friendly vaccine production

6. Challenges in Plant-Based Vaccine Development

6.1. Production Challenges

Low and inconsistent protein yields remain a major issue in plant-based vaccine development. Expression levels vary with plant species, environmental conditions, and transformation methods, making it difficult to standardize production. Unlike controlled mammalian cell systems, plants are affected by temperature, light, and soil quality. Moreover, overexpression of foreign proteins can disrupt plant metabolism, reducing both yield and plant health. Ongoing research focuses on optimizing expression vectors, promoters, and growth conditions to improve stability and output.

6.2. Downstream Processing

Purification of plant-derived vaccines is complex and expensive due to the presence of other plant compounds. Achieving consistent glycosylation and protein folding is difficult, which can affect vaccine quality and immune response. Standardizing purification and quality control remains a major bottleneck for large-scale production.

6.3. Regulatory Hurdles

Regulatory frameworks, designed for conventional vaccines, pose difficulties for plant-based products. Approval processes for genetically modified plants are lengthy and costly, with strict testing for environmental safety, allergenicity, and efficacy. This slows the market entry of plant-derived vaccines.

6.4. Public Acceptance

Public skepticism toward genetically modified organisms (GMOs) is another barrier. Misconceptions about safety and ethics often hinder acceptance of plant-based vaccines. Greater public education, transparency, and awareness are needed to build trust and promote adoption.

7. Recent Innovations in Molecular Farming

Recent advances are transforming plant-based vaccine development, enhancing yield, safety, and delivery.

7.1. Gene Editing (CRISPR)

CRISPR-Cas9 allows precise modifications in plant genomes, optimizing traits for higher antigen yield, stability, and human-compatible glycosylation. It can remove unwanted traits, improve promoters, and accelerate plant modification, addressing key challenges in plant-based vaccine production.

7.2. Nanoparticle-Based Delivery

Nanoparticles, including lipids, polymers, and VLPs, protect vaccine antigens, enhance stability, and enable controlled release. They improve oral or mucosal delivery, making vaccines non-invasive and cost-effective. Encapsulating plant-derived antigens in nanoparticles can also support edible vaccines with better bioavailability.

7.3. Artificial Intelligence (AI)

AI optimizes plant vaccine production by analyzing genomic and environmental data to maximize antigen expression. Machine learning accelerates plant line selection, growth condition optimization, and prediction of safety risks, speeding up R&D and regulatory approval.

These innovations—CRISPR, nanoparticles, and AI—together improve efficiency, consistency, safety, and delivery of plant-based vaccines, expanding the potential of molecular farming for rapid and scalable vaccine production.

8. Future Directions

Plant-based vaccines are poised for personalized medicine, producing patient-specific antigens for cancer or autoimmune therapies, combined with CRISPR and bioinformatics for cost-effective, scalable production. Nanoparticles can enhance stability and immune response, while synergy with mRNA or other platforms broadens applications. Beyond human vaccines, plant systems may serve in diagnostics and chronic disease immunotherapies. Their rapid, scalable production can address global health inequities and improve pandemic preparedness.

Conclusion

Plant-based expression systems offer a cost-effective, scalable, and versatile platform for producing both pharmaceutical and non-pharmaceutical proteins. While technical challenges have largely been addressed, regulatory barriers remain the main obstacle to widespread adoption, particularly for therapeutic proteins. With demonstrated production capabilities, economic feasibility, and ongoing technological advancements, plant-made biologics hold significant promise for the future of sustainable and efficient biomanufacturing worldwide.

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CRISPR - GENE EDITING IN CROPS

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Summary

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) is a tool for editing genes that lets you change DNA in plants very accurately. It was based on a natural way that bacteria protect themselves. CRISPR uses a guide RNA (gRNA) to find a specific DNA sequence and a Cas9 enzyme to cut the DNA at that spot. After that, the cell fixes the cut, which can add, remove, or replace genes. This system has been used to get new germplasma resources through gene-directed mutation because it is easy to use and works well at causing mutations. CRISPR-Cas9 editing can quickly create new germplasm resources to improve important agronomic traits because whole-genome sequencing data and information about gene function for important traits are now available. CRISPR is changing the way we improve crops by making it possible to make precise, quick, and long-lasting changes to their genes to solve problems with food security, climate change, and nutrition. We look at this technology and how it can be used on fruit and vegetable crops in this review. We talk about the problems, the different types that are already out there, the rules that go along with them, and what they could be used for in the future.

INTRODUCTION

The world's agricultural systems are under a lot of stress because the population is growing and people need more food. This problem is made worse by climate change, which is causing more extreme weather, changes in the way pests and diseases spread, and less land that can be used for farming (Bibi and Rahman, 2023). These changes put crops at risk and make farming less stable, which makes it harder to make sure that everyone has enough food. While traditional breeding methods have greatly improved agriculture in the past, they are often too slow to keep up with these rapid changes in the environment. Genetic engineering, on the other hand, has had problems with accuracy and public acceptance (Afzal et al., 2023; Ambika et al., 2024). Rice, wheat, maize, and soybeans are staple crops that are the basis of global food security. They are the main source of calories for a large part of the world's population (Morrow et al., 2023). These crops are very important for people to eat, but they are also very important for feeding animals and for use in industry. Climate change, pests, and diseases are making these important crops less productive and less able to withstand stress. To make sure there is enough food for everyone, it is important to improve the yield, nutritional value, and stress tolerance of staple crops.

This is especially true as the world's population grows and arable land becomes less available. The development of agricultural technology from selective breeding to advanced genetic tools shows that we are still working to solve these problems. CRISPR/Cas technology has changed the game in agricultural biotechnology by being a revolutionary tool for editing genomes. CRISPR/Cas systems are a revolutionary tool for targeted genome editing that has changed both basic and applied research in agriculture. The CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) mechanism was first found in the adaptive immune systems of bacteria and archaea. It uses a guide RNA (gRNA) to direct the Cas (CRISPR-associated) nuclease to a specific DNA sequence, where it makes a precise double-strand break. The cell's natural DNA repair mechanisms then fix this break, which lets scientists make specific changes to the genome. CRISPR/Cas systems are easier to design, work better, and cost less than earlier genome editing tools like Zinc Finger Nucleases (ZFNs) and Transcription Activator-Like Effector Nucleases (TALENs). This makes them very useful for a wide range of crop improvement tasks. Finding the CRISPR/Cas system as a genome editing tool was not only about finding it in bacteria, but also about figuring out how to use it and improve it for use in more complicated organisms. Early studies elucidated the essential functions of crRNA (CRISPR RNA) and tracrRNA (trans-activating crRNA) in directing the Cas9 protein for accurate DNA cleavage, which was instrumental in transforming CRISPR/Cas into a multifaceted genome editing tool (Jung et al., 2024). The process starts with the guide RNA binding to the target DNA sequence to make an RNA-DNA hybrid. This directs the Cas9 protein to the right part of the genome. When Cas9 gets there, it makes a double-strand break, which the cell's natural DNA repair pathways fix. These pathways are either non-homologous end joining (NHEJ) or homology-directed repair (HDR) (Yuan et al., 2024). This in-depth knowledge of how CRISPR/Cas works shows how well it works for making precise and efficient changes to the genome. It is a key technology for improving crop traits and solving global problems like climate change and food insecurity (Raza et al., 2024). CRISPR technology has become a game-changing tool that makes it possible to quickly create new crop varieties with better traits, such as better resistance to biotic and abiotic stresses, higher nutritional value, and more potential for higher yields. Additionally, CRISPR/Cas systems improve agricultural productivity and sustainability because they are simple, flexible, cheap, and acceptable to the public because they can make precise changes without adding foreign DNA (Ali et al., 2023). Recent developments, like prime editing and base editing, have made genome editing even more accurate and useful. This means that it can be used to make more complex genetic changes with fewer unintended effects. These new ideas are making it possible for the next generation of crops to grow well in changing weather and meet the needs of a growing population. This review seeks to furnish a thorough examination of CRISPR/Cas technology in augmenting crop resilience and the productivity of staple grains in the face of climatic adversities. This article discusses how CRISPR/Cas systems could change modern agriculture by looking at the most recent research and technological advances. It would give us a complete picture of how to understand new technologies and find strategic paths for future research and development, which would help make sure that food is safe around the world and that farming is done in a way that is good for the environment.

MAIN BODY

Recent improvements in CRISPR technology have made genome editing much more specific and effective, which is very important for agricultural uses. Prime editing and base editing are new ways to make precise changes to genes that are very important. Prime editing uses CRISPR-Cas9 and a reverse transcriptase to fix up to 89% of known genetic variants. This lets you directly edit target DNA sequences. Research has shown that it works to make rice more resistant to disease by fixing certain point mutations without breaking double strands (Gupta et al., 2023). On the other hand, base editing makes it possible to change one DNA base into another directly and permanently, which makes point mutations more accurate. Applications encompass the modification of flavour profiles in peas and tomatoes, as well as the enhancement of cold tolerance in soybeans through the alteration of genes involved in fatty acid desaturation and cold response pathways (Nizampatnam et al., 2024). New CRISPR-associated proteins like Cas12 and Cas13 add to the tools that agricultural biotechnology can use. Cas12 is good for multiplex editing because it lets you change multiple traits at once. For example, it can help soybeans have multiple disease resistance genes (Sun et al., 2024). Cas13d is a very strong way to interfere with multiple RNA viruses in potato crops. This makes it a useful tool in the ongoing efforts to improve agricultural productivity and sustainability (Zhan et al., 2023). For genome editing in plants to work, CRISPR components must be delivered quickly and easily. Recent methodologies encompass nanoparticle-mediated delivery, which safeguards CRISPR components from degradation and augments cellular uptake, thereby significantly enhancing trait improvement in maize (Chakraborty et al., 2023; Yau et al., 2024). Viral vectors, utilising inherent viral infection processes, have demonstrated enhanced efficacy and safety in transient expression initiatives, such as the induction of virus resistance traits in tobacco and tomato (Jogam et al., 2023; Wang et al., 2024e). The ribonucleoprotein (RNP) complex delivery method sends CRISPR parts directly as proteins and RNA, which lowers the chance of unwanted effects. This method has worked well in crops like wheat to make them more resistant to disease and increase their yield (Poddar et al., 2023). Improved computational tools for accurate guide RNA design and the creation of high-fidelity Cas variants show less off-target activity (Zhang et al., 2023b). In wheat, high-fidelity Cas9 variants have been used to lower the number of unintended mutations and make the plants more resistant to drought. These improvements make genetic edits safer and also make CRISPR more useful for creating crops that can survive in changing climates. The ongoing improvement of CRISPR technologies, such as new ways to deliver and edit them, is making it possible for agriculture to make big changes, as shown in Table 1. Researchers are making these tools more accurate and useful, which opens up new ways to use CRISPR and helps create agricultural systems that are stronger, more productive, and more sustainable. The use of CRISPR/Cas technology in farming has a lot of promise for making grain crops more resistant to different types of abiotic and biotic stress (Yadav et al., 2023). This section examines how recent progress in CRISPR/Cas technology has improved the resilience of grain crops to these stresses, thereby promoting sustainable agricultural productivity amid climate change and other environmental challenges. CRISPR/Cas genome editing has evolved into a sophisticated technique for enhancing crop growth, development, and stress responses, as demonstrated in. In this context, we examined recent progress in CRISPR-mediated crop enhancement under abiotic and biotic stresses, as well as enhancements in various growth-related traits.

IMPROVING CROP YIELD-

CRISPR/Cas technology provides novel avenues to augment crop yield by directly targeting genes that govern plant growth and development. Editing the OsAPL gene that helps move nutrients around has been shown to increase rice yield (Zhang et al., 2024a). Targeting genes that are involved in making chlorophyll and capturing light, like the OsSXK1 gene in rice, has made photosynthesis more efficient, which has led to higher photosynthetic rates and more grain yield (Zheng et al., 2021). Editing genes that help plants take in and use nutrients, like the ARE genes in barley or wheat, also makes plants use nitrogen more efficiently and gives them higher yields when nitrogen levels are low (Karunarathne et al., 2022). Recent research has shown that CRISPR/Cas technology can improve yield-related traits in a number of crops. Editing the DEP1 gene in rice has resulted in the creation of semi-dwarf varieties characterised by enhanced lodging resistance and increased grain yield (Zhang et al., 2023a).

IMPROVING CROP QUALITY-

CRISPR/Cas9 technology has made agricultural biotechnology much better by allowing for precise genome editing that can improve the safety, taste, texture, shelf life, and industrial use of many crops. Researchers have used CRISPR/Cas9 to change the CYP79D1 gene in cassava. This has greatly reduced the amount of cyanogenic glycosides, which lowers the risk of cyanide poisoning and makes this important crop safer without affecting its agronomic performance (Juma et al., 2022). The technology has been used in rice to make it smell better by changing the OsBADH2 gene, which makes more 2-acetyl-1-pyrroline (2-AP), a compound that gives off a pleasant smell that people like (Tian et al., 2023). The gbss gene in potatoes has been changed by CRISPR/Cas9, which makes amylose-free starch that has a smoother texture. This is very useful in both cooking and industrial processes. The technology has also been very important in making different crops last longer by targeting genes that are involved in the ripening process, like those that control ethylene production. This slows down the ripening process, lowers post-harvest losses, and makes the crops more economically viable. Also, in barley, CRISPR/Cas9 has been used to make the grains harder by changing the Hina gene. This makes the grains better for industrial use because they have a higher hardness index, but it also makes the grains thinner and heavier (Jiang et al., 2022). Also, in potatoes, targeting the FtsZ1 gene has led to the creation of lines with bigger starch granules. This has greatly increased the viscosity of starch paste, making these potatoes better for certain industrial processes, all without changing the plant's overall phenotype or nutritional quality. These different uses of CRISPR/Cas9 show how it could change the way crops are grown by allowing for changes that meet consumer needs, improve safety, and meet specific industrial needs while still making sure that farming practices are sustainable and profitable.

NUTRITION ENHANCEMENT

One of the main goals of agricultural biotechnology is to fix nutritional deficiencies by biofortifying crops. CRISPR/Cas technology is a key part of making this happen. For example, CRISPR/Cas has been used to raise the pro-vitamin A content in rice, which is an important step in fighting vitamin A deficiency in people who eat a lot of rice (Maiti and Banik, 2023). Biofortification seeks to enhance the nutrient density of crops, thereby augmenting their nutritional value. Researchers changed the genes that make pro-vitamin A to make "Golden Rice," which has more beta-carotene (Dong et al., 2020; Datta et al., 2021). People have also used RISPR/Cas technology to make crops richer in minerals. Genes like OsNAS have been changed in rice and wheat to raise the levels of iron and zinc. This fixes micronutrient deficiencies that can cause anaemia and make the immune system work less well. In maize, targeting the PSY1, Crtl, and LCYB genes has also increased the production of pro-vitamin A, which has led to the creation of "Golden Maize." The technology also helps crops have more amino acids. CRISPR/Cas has been used to boost the levels of important amino acids and vitamins in cassava, which has greatly improved the nutritional value of this important crop (Otun et al., 2023). Editing genes that are involved in lysine biosynthesis has made maize have more lysine, which is a common problem with cereal grains (Hasan, 2024). Another important goal of CRISPR/Cas technology is to make crops' proteins better. For instance, mutagenesis aimed at the OsAAP6 and OsAAP10 genes in rice can lower the protein content of the grains, which makes the crop taste better and cook better (Wang et al., 2020). By targeting the GmIPK1 gene, CRISPR/Cas technology has been able to lower the levels of antinutritional substances like phytic acid in soybeans. This has made iron and zinc more available to the body, which has improved the overall nutritional quality of the soybeans (Song et al., 2022).

CONCLUSION

The fast development of CRISPR/Cas technologies has brought about a new era of precision agriculture. These technologies allow for targeted genetic changes that make crops stronger, more productive, higher quality, and more nutritious. New techniques like prime editing and base editing have made genome editing much more precise and useful. They let you fix genetic variants and fine-tune traits without causing double-strand breaks. Adding Cas12 and Cas13 proteins to the CRISPR toolkit and using new delivery methods like nanoparticle-mediated systems and ribonucleoprotein complexes has made these tools even more useful for a wider range of crop species.

These improvements have been very helpful in solving important problems in agriculture, such as making plants more resistant to disease and stress, improving traits related to yield, and making food safer and better. CRISPR/Cas technology has also become a powerful tool for biofortification. It helps fight global nutritional deficiencies by adding important vitamins, minerals, and amino acids to crops. As computational tools and high-fidelity Cas variants keep improving the accuracy and safety of genome edits, CRISPR/Cas is ready to change the way we farm in a way that is good for the environment. These technologies are not only meeting current needs, but they are also laying the groundwork for a more secure and fair global food system by allowing the creation of crops that can withstand climate change, have more nutrients, and are useful in industry.

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NATURE'S MOSAIC: DIRT-FREE FARMING

Summary

Because the population is growing, the depletion of land and water resources has become a problem. This is affecting the availability of these resources and causing degradation, which is a major threat to ecological balance and sustainability. By 2050, the world's population is expected to exceed 9.8 billion, accompanied by a concerning decline in agricultural land and the degradation of fertile soil due to industrialisation, urbanisation, and climate change. Soilless farming is a groundbreaking method of sustainable agriculture that uses new ways of growing crops to solve important problems with food security. There are three main methods in this system: hydroponics, where plants grow in water that is rich in nutrients; aeroponics, where roots are suspended in air and misted with nutrients; and aquaponics, which combines fish farming with plant growing in a way that benefits both. These methods have many benefits, such as less water use, no diseases that live in the soil, and year-round production. Soilless farming is a good way to feed city dwellers by using vertical spaces and rooftops. It also makes the most of limited land space, which is a problem in many cities.

Introduction

Soil has always been essential to the growth of plants in traditional farming practices. On the other hand, keeping up with global food production has become increasingly difficult due to factors such as climate change, shrinking arable land, and increased population pressure. According to estimates provided by the Food and Agriculture Organisation (FAO, 2022), nearly one-third of the world's soil is degraded as a result of factors such as salinity, erosion, and using an excessive amount of chemicals.

Both scientists and farmers are looking into soilless farming as a potential solution to these challenges. This type of farming allows crops to be grown in controlled environments without the use of soil. The use of this method, which can be implemented in greenhouses, vertical farms, and even in areas that are not suitable for conventional agriculture, contributes to the maintenance of food security in the face of environmental shifts.

Main Body

1. What is Soilless Farming?

Soilless farming is when plants are grown in nutrient solutions instead of soil. This is the most common kind of system:

Hydroponics: It is a way to grow plants using a nutrient solution that is either water or an inert medium like perlite or coco peat.

Aeroponics: It is a method of growing plants in which the roots are suspended in the air and sprayed with a nutrient mist. This increases the amount of oxygen in the air and speeds up growth.

Aquaponics: It is a type of farming that combines hydroponics and fish farming. Fish waste is used to feed the plants.

These systems allow precise control of nutrients, water, and light, helping plants grow faster and healthier.

2. Advantages of Soilless Farming

Soilless farming has several benefits over traditional methods:

Water Efficiency: It uses up to 90% less water than soil-based agriculture since water is recycled and reused (Resh, 2013).

High Yield and Quality: Plants get optimal nutrients, which leads to faster growth and higher productivity (Jensen, 1997).

Space Saving: Vertical farming and compact hydroponic setups enable cultivation in urban areas, rooftops, and small greenhouses (Despommier, 2010).

Reduced Pesticide Use: The lack of soil reduces pest and disease issues, resulting in cleaner and safer food.

Year-Round Cultivation: Controlled environments make farming independent of seasons and weather.

These features make soilless farming great for cities and regions with poor soil or limited water resources.

3. Challenges and Limitations

Despite the many benefits, soilless farming is not without its difficulties. There is a possibility that hydroponic and aeroponic systems will have a high initial setup cost, and that maintaining them will require extensive technical expertise. There is an increase in operational costs due to the use of electricity for pumps, lights, and climate control. Furthermore, not all crops are suitable for soilless systems; for example, root vegetables and large fruit trees are more difficult to cultivate using this method (Khandaker & Kotzen, 2018). In spite of this, these systems are gradually becoming more accessible and sustainable as technology continues to advance and the cost of renewable energy continues to decrease.

Climate and water

The unpredictability of the weather, which includes an increase in the frequency of droughts and floods, presents difficulties for both the irrigation of crops and their growth.

The use of pesticides to combat outbreaks poses a persistent risk to the environment and beneficial soil organisms such as earthworms and fungi. In addition, the use of pesticides can be harmful to the environment.

In addition to contributing to soil contamination and imbalance, the excessive use of synthetic fertilisers and pesticides is also detrimental.

4. Global Examples

A number of nations have adopted soilless farming as a means of addressing issues related to food security. For example, the Netherlands makes use of sophisticated hydroponic greenhouses to efficiently produce vegetables while utilising a small amount of land. Vertical farming projects such as Sky Greens have been established in Singapore with the goal of cultivating local produce in urban areas with limited space.

There are large-scale aeroponic farms in the United States, such as AeroFarms, which use 95% less water than conventional farming methods.

These examples demonstrate how soilless farming has the potential to transform urban food systems and reduce reliance on fruits and vegetables that are imported.

Conclusion

Farming without soil is a significant step forward in terms of producing food in a way that is both sustainable and efficient. The removal of soil contributes to the conservation of water, the preservation of space, and the facilitation of continuous cultivation in a variety of environments. It is evident that the technology offers benefits in terms of both productivity and environmental conservation, despite the fact that it requires an initial investment and expertise. As the world's population continues to increase and natural resources continue to diminish, soilless farming presents an opportunity for innovation that will be essential in the future to ensure both food security and environmental resilience.

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ARTIFICIAL INTELLIGENCE FOR SEED QUALITY: HOW MACHINE LEARNING IS TRANSFORMING AGRICULTURE

Abstract

In agriculture, the quality of seeds has a direct impact on seed germination, crop health, and yield. Both manual inspections and laboratory tests are labor-intensive, time-consuming, and prone to errors. Using machine learning (ML), a subset of artificial intelligence, seed quality can be evaluated quickly, accurately, and nondestructively. In addition to analyzing the processing images, spectral data, and phenotypical traits, ML models can assess seed size, shape, viability, broken rate, and germination potential. These technologies enhance efficiency and accuracy, supporting informed decision-making in precision agriculture. In this study, machine learning is applied to seed quality assessment, emphasizing its advantages and potential for modernizing agriculture.

Keywords: Artificial Intelligence, Machine Learning, Computer Vision, Seed Quality, Precision Agriculture

1. Introduction:

Seed the most vital and fundamental part of the life cycle of various crops and the foundation of many technological measures in agricultural science, seeds are among the most important assets for agricultural production [1]. Maintaining stable grain and agricultural output is essential to ensuring global food security in the face of a rapid population growth and continuing impacts of the COVID-19 pandemic [2]. The decline in seed vigor is generally attributed to internal physiological regulation or external environmental stress [3,4]. With the development of digital agriculture technologies, like machine learning (ML), deep learning has become a revolutionary method for improving the effectiveness and precision of seed quality assessment. Seed Quality in the seed industry are time-consuming and detrimental to determining group quality by using various techniques to enhance seed characteristics through batch rejection and strength. In fact, there is a growing need for efficient methods that can offer a quick, precise, non-destructive, and impartial manner to assess the quality of seed. [6]. Seeds usually lose viability and vigor in conjunction with changes in chemical composition and internal anatomical factors that aren't always visually identifiable [7]. Additionally, relevant data associated with seed quality characteristics have been collected successfully through imaging methods, such as X-ray imaging and high-resolution imaging [8]. For example, FT-NIR spectroscopy has shown great promise in detecting the biological and chemical composition of seeds through extensive spectral acquisition and data analysis. [9].

2. Important of Seed quality in Agriculture: Machine learning is a one the branch of artificial intelligence that works by using a different algorithms coding that learn from large amounts of data to perform various types of segmentation and pattern recognition, they can be identifying a better decision-making capability in a less human arranged background.

Machine learning is being used very rapidly among farmers to understand the value of a group of seed. It is being used in a good way in large-scale agricultural dataset, as well as in a simple way to evaluate image processing as a classification to get good results, through which we can get good quality batches.[11]. With a good model, we can easily determine the quality parameters of the group of seed, including size, color, moisture, broken parts of seed, as well as biological chemical properties, through large-scale images analysis.; spectral analysis can assist in determining seed viability or seed germination potential. These AI-based evaluations provide a superior method for assessment of seed quality that is faster, more accurate, and more efficient, especially compared to traditional methods, thus contributing greatly to modern precision agricultural processes [12]. With AI-based, we can achieve a high-quality consignment and prove the fastest and most accurate way, especially compared to our traditional method, we can get a good result very quickly.

Figure 1: Importance of Machine Learning in Agriculture:

1. **Machine Learning Techniques Assessment Using Seed Quality**:

There are Several ML approaches have been advanced and improved to provide good quality seed assessment in agricultural farming practices.

3.1. Image Analysis: High-resolution imaging combined with Convolutional Neural Networks (CNNs) to perform automated, in-depth analysis of seed quality machine learning to easily analyze different types of images, such as the color of seed, texture, and even the effects of diseases. This allows for the precise detection of issues that would typically require the judgment of a trained machine learning models expert, but does so with greater speed, consistency, and scalability. [13].

3.2. Preprocessing of Images: The preprocessing including contrast enhancement of image seed, the system isolates the seed for precise digital examination of quality. It then automatically extracts critical physical attributes shape, size, and surface properties delivering rapid and objective results. [14, 15].

3.3. **Analyzing Spectral:** Seeds by analyzing its throughput through different spectra, we can classify its easy chemical composition, moisture content, and disease severity. [16] Support Vector Machine is a general type of machine learning model through which we use different types of spectrum analysis. [17].

3.4. **Predictive Modeling:** Machine learning algorithms have the potential to predict seed quality, including seed germination rate, seed vigor, and other important seed quality parameters, using historical data. For the purpose of developing these predictive models, regression, decision trees, random forests, and neural networks are frequently utilized techniques. [18].

3.5. **Natural Language Processing (NLP):** Natural language processing (NLP) methods are capable of processing text data from labels dataset, records, or quality reports to identify valuable information related to the seed quality determination. This would be valuable in laboratories that are automated seed testing or are required to process large volumes of text data quickly. [19]

2. **Machine Learning Applications in Seed Quality Assessment:**

There are many applications in seed quality assessment ML can be divided into the following categories

4.1 **Seed Viability Assessment:** Machine learning algorithms can be easily analyzed in an efficient way by the digital image processing and its characteristics, and with advanced models such as CNNs, which can detect differences that cannot be distinguished even by a human inspector, and give us faster and more effective results. [20].

4.2 **Seed Moisture Content Determination**: Seed Moisture content is a key critical parameter affecting seed germination, seed storage, and overall seed quality. Combined with image analysis or spectral data, can estimate moisture levels non-destructively Machine learning models can predict seed moisture content accurately without destructive testing, offering faster and more reliable results than traditional laboratory methods.[21].

4.3 **Seed Pest and Disease Detection:** The Bad seed with very low yield, but today's modern techniques of machine learning have a type of model like, Support Vector Machines (SVMs) and Deep Learning models, through which we can easily identify the seed identification and we can find out whether it has a fungal infection or a bacterial infection. [22, 23, 24].

4.4 **Seed Purity Analysis**: The analyze of the different types of good quality and bad quality seed through different models of machine learning, these models classify it based on spectroscopy so that we can ensure a high-quality batch seed to become good production. . [25].

4.5 **Seed Germination Quality Prediction:** Seed germination is important parts of production, if we analyze seed well through machine learning, it's become increase in production and at the same time the quality of the set germination will be good. [26].

4.6 **Multi-Modal and Integrated Assessment of Seed Quality:** Advanced machine learning approaches combine image processing, spectral, and text data to provide an assessment of seed quality determination that is more comprehensive. Multi-modal models, therefore, provide more accurate and dependable predictions that combine parallel and complementary sources of information.[27].

3. **Important Models of Machine Learning for Seed Quality Analysis**

ML encompasses different models, each with its own advantages and applications.

5.1 Support Vector Machines (SVM): SVM are the types of machine supervised learning (MSL) models that can be used to classify regression tasks related to seed quality detection. They are classification into the 3rd high-dimension spaces and can manage non-linear relationships between variable quantity. In seed quality determination have been implemented to classify seeds based on spectral data, morphological traits, and other seed quality characteristics. [28]

5.2. Random Forests: Random forest (RF) model which is used for training the seed quality of the group evaluate various characteristics of seed it can estimate its germination and other quality metrics. It is a part of the ML model that allows us to make good decisions through large amounts of data in a short time so that the average analysis, moisture content prediction and germination rate estimation on seed quality [29,30].

5.3. Convolutional Neural Networks (CNNs):

Convolutional Neural Networks the class of deep learning models to designed image analysis in various crops field in agriculture as well in laborites. This is also an important part of machine learning that can analyze and understand different types of image layers, such as edge quality, texture, broken rate, shape, and shape. It can examine images and detect seed, good quality seed, classify seed types and assess seed viability achieved an accuracy of over 95%, the strong potential of CNNs in automating seed quality assessment. [31]

5.4. **K-Nearest Neighbors (KNN):**

K-Nearest Neighbors advances machine learning commonly used both for classification and regression tasks on fields. It can be identifying the 'k' closest data points to a given query point and making predictions based on the majority labels of these neighbors. The model achieved high correct accuracy seed quality assessment on the base of seed classify types, defects seed. [32,33]

5.5. **Artificial Neural Networks (ANNs):** It is one of the advanced models capable of learning and representing complex nonlinear relationships between seed features and their corresponding quality categories, thereby enabling more accurate and efficient seed quality classification and supporting better decision-making for crop production.[34].

4. **Seed Quality Determination Advantages of Machine Learning**

Machine learning provides many important benefits in batch production farming systems, which we will describe below.

6.1 **Automation and Efficiency:** Machine learning, the key task is to divide the filtering and classification system in an important way in the quest for seed quality and at the same time show a significant performance in a short time improving our seed quality system.

6.2 **Speed and Efficiency:** ML algorithms can process large amounts of dataset, which takes a significant portion of the time to analyze, and gives us a good result while maintaining quality of seed.

6.3 **Scalability and Adaptability:** Once trained, the model can accurately and easily estimate the group and through pre-processing of seed quality imaging it can be evaluated in different ways and can be cast according to the desired conditions.

6.4 **Cost-Effectiveness**: The machine learning Technology can reduce labor costs and our investment in a clean environment, the fastest processing and the best accuracy can provide a good resolution.

6.5 **Early Detection of Defects:** Machine learning can identify fine results that even can't not visible the human necked eye, improving early detection of low-quality seeds detection.

5. **Challenges and Limitations:** To assess the quality of the seed, it is necessary to have a large quality data set and at the same time, we can be able to extract features well based on good software. Modern models such as relationship Neural Networks may be superseded and may also require too much computer resources and there are other models that cannot get good results from our data set So if we are going to make improvements, we may for example need lighting and image processing and a modern type of computer and good software of high quality that can increase our rate.

6. **Future Directions:** Machine learning to improve seed quality through image processing and feature detection, assess ways a robot can enhance the operation of our precision agriculture system, and improve the deep learning model even further, where

machine learning will be even more impactful in increasing the production of our farming operation. Researchers are encouraged to develop cost operative and adaptable machine learning solutions that can be applied across a wide range of agriculture farming systems, ensuring accessibility and practicality for diverse agricultural environments.

7. **Conclusion:** Machine learning plays a common role in the quality of the seed and in the production of the agricultures. In today's era, compared to labor, machine learning provides us with the most timely and fastest performance of the quality of the seed and at the same time, in less time we can improve the quality of anything quickly and with less input into the agricultural particles. Due to modern technology, our food production has also increased significantly. In this review, we will discuss how we can improve the quality of the set through machine learning and make it a common tool in agriculture.

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HYBRID NANOFLUIDS FOR ENHANCED THERMAL PERFORMANCE: RECENT DEVELOPMENTS AND AGRICULTURAL APPLICATIONS:

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Abstract:

Hybrid nanofluids—engineered suspensions of two or more distinct nanoparticles within a base fluid—have emerged as a powerful solution for improving thermal management in diverse engineering and agricultural systems. This research paper reviews recent developments concerning hybrid and ternary hybrid and nanofluids, including synthesis techniques, thermophysical properties, and agricultural applications. Emphasis is given to spectrum-selective nanofluids designed for the greenhouse thermal regulation. The study also integrates a Navier–Stokes-based formulation to model hybrid nanofluid flow and heat transfer mechanisms. The review highlights enhancement mechanisms, stability challenges, sustainability issues, and future prospects.

Keywords: Hybrid nanofluid, Ternary hybrid nanofluid, Nano fluid, Navier–Stokes equations, Thermal conductivity, Greenhouse cooling, Agricultural applications

1. Introduction

Efficient heat transfer plays a role in renewable energy and agricultural processes. Conventional fluids such as water and ethylene glycol exhibit limited thermal conductivities, restricting their heat-transfer capacity. Nanofluids, which are suspensions of nanosized particles in base fluids, have been introduced to overcome these limitations.

Hybrid nanofluids (HNFs) consist of two or more distinct nanoparticles (e.g., metal–metal oxide, metal–carbon) dispersed in a base fluid. Their combined thermal and stability properties often outperform those of single-component nanofluids (Kshirsagar et al., 2021; Kalsi, 2025).

With increasing focus on sustainable agriculture, spectrum-selective nanofluids—capable of filtering infrared radiation and transmitting visible light—have emerged as efficient greenhouse cooling and solar energy materials (Sajid & Bicer, 2023; Qu et al., 2024).

2. Synthesis and Stabilization Methods

Hybrid nanofluids are prepared using **two main approaches**:

1. **Two-step method:** Nanoparticles are first synthesized or purchased, then dispersed into the base fluid using ultrasonication and surfactants (PVP, SDS, CTAB).
2. **One-step method:** Nanoparticles are synthesized directly in the base fluid, leading to better dispersion and reduced oxidation (Manimaran, 2025).

Stabilization is critical for performance. Approaches include surface functionalization, pH adjustment, and ultrasonic agitation. Green and bio-based synthesis using plant extracts has gained popularity for reducing toxicity and cost (Rashid et al., 2024).

3. Thermophysical Properties and Mechanisms

The thermophysical behavior of hybrid nanofluids depends on nanoparticle concentration, shape, and dispersion.

- **Thermal conductivity:** Hybrid nanofluids typically show 25–60% higher thermal conductivity than base fluids at 1 vol% nanoparticle loading (Shah et al., 2024).
- **Viscosity:** Increases by 5–20%, depending on particle loading and surfactant use (Rashid et al., 2024).
- **Mechanisms:** Brownian motion, particle clustering, percolation networks, and liquid layering all contribute to enhanced thermal conductivity.

Ternary hybrids such as Cu–Ag–Al_2O_3 and TiO_2–SiO_2–Cu exhibit synergistic effects that further enhance heat-transfer capability (Adun et al., 2024).

4. Characterization Techniques

Key techniques used to study hybrid nanofluids include:

- **Thermal conductivity:** Transient hot-wire or plane-source methods;
- **Viscosity:** Rotational rheometers;
- **Stability:** Zeta potential and UV–Vis spectroscopy;
- **Structure:** SEM, TEM, and XRD analysis;
- **Optical characterization:** UV–Vis–NIR spectroscopy for spectrum-selective nanofluids (Scott et al., 2022).

Recent reviews emphasize the need for **standardized procedures** to ensure data comparability across laboratories (Manimaran, 2025).

5. Recent Developments (2019–2025)

Machine learning (ML) and artificial intelligence (AI) have been applied to predict optimal nanoparticle combinations and thermal properties (Qureshi et al., 2025; Shao, 2025). Experimental and numerical studies (Ullah, 2025; Adun et al., 2024) demonstrated improved heat transfer in Cu/Ag/Al_2O_3 and TiO_2–SiO_2–Cu ternary hybrid nanofluids.

In agricultural contexts, spectrum-selective nanofluids have shown the ability to **reduce greenhouse cooling loads by up to 30%**, allowing for energy-efficient temperature regulation (Sajid & Bicer, 2023; Qu et al., 2024).

6. Mathematical Modeling — Navier–Stokes Formulation for Hybrid Nanofluids

Modeling hybrid nanofluid flow and heat transfer is essential to link laboratory data with real-world performance. The **Navier–Stokes equations** govern the motion of incompressible fluids and can be adapted using effective properties for hybrid nanofluids.

6.1 Governing Equations

Continuity Equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

Momentum Equation

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\frac{\partial u_e}{\partial t}+u_e\frac{\partial u_e}{\partial x}+\nu_{mnf}\frac{\partial^2 u}{\partial z^2}+[g\beta_{mnf}(T-T_\infty)]\frac{x}{l}$$

Energy Equation

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\frac{K_{mnf}}{(\rho C_p)_{mnf}}\frac{\partial^2 T}{\partial z^2}+\frac{Q_0}{(\rho C_p)_{mnf}}(T-T_\infty)$$

6.3 Computational Implementation

Simulations use the finite-element method (e.g., ANSYS Fluent, COMSOL Multiphysics, or Open FOAM).

- **Boundary Conditions:** No-slip at walls, specified heat flux or constant wall temperature.

- **Validation:** Compare with experimental Nusselt number and pressure-drop data (Sajid & Bicer, 2023; Adun et al., 2024).
- **Applications:** Used to predict temperature distribution in greenhouse glazing channels and optimize nanoparticle ratios for maximum thermal transport.

6.4 Coupled Radiative Effects

In spectrum-selective nanofluids, radiative heat transfer is significant. A simplified form couples the energy equation with a volumetric absorption term:

$\frac{\partial T}{\partial t} = \alpha \frac{K_{mnf}}{(\rho C_p)_{mnf}} \frac{\partial^2 T}{\partial z^2} + \frac{Q_0}{(\rho C_p)_{mnf}} (T - T_\infty)$ Such coupled Navier–Stokes–radiation models accurately predict greenhouse temperature reductions achieved by nanofluid-based glazing systems (Qu et al., 2024).

7. Agricultural Applications

Hybrid nanofluids offer several agricultural advantages:

- **Greenhouse climate control:** Spectrum-selective nanofluids can block infrared while transmitting visible light, reducing internal heat load (Sajid & Bicer, 2023).
- **Solar collectors:** Improved heat transfer and energy conversion efficiency.
- **Thermal storage:** Enhanced charging/discharging rates due to high thermal conductivity.

8. Sustainability and Safety

Environmental sustainability and worker safety are vital considerations. Biocompatible synthesis routes and closed-loop systems are recommended to prevent nanoparticle leakage. Life-cycle assessments (Sajid & Bicer, 2024) confirm that nanofluids can offer net environmental benefits if recycled effectively.

9. Future Prospects: Future research should emphasize:

Standardized testing protocols;AI-guided formulation optimization;Scalable green synthesis;Long-term stability studies;CFD–experimental integration for agricultural applications.

10. Conclusion

Hybrid nanofluids present a transformative opportunity for enhanced heat transfer in industrial and agricultural systems. Their tunable thermal and optical characteristics make them ideal for greenhouse cooling and solar collectors. Using Navier–Stokes modeling provides deeper insight into the coupled flow–heat–radiation behavior, enabling predictive optimization and design of sustainable agricultural technologies.

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WORLD TRADE ORGANISATION (WTO)

INTRODUCTION OF WTO

The WTO was born out of the General Agreement on Tariffs and Trade (GATT). WTO is an international body to supervise and encourage international trade. The Uruguay Round of trade talks concluded in 1994 resulted in setting up of the World Trade Organization (WTO) to take over the functioning of GATT for encouraging multilateral trade in goods and services. The WTO began functioning on 1st January, 1995. The Headquarters of WTO at Geneva, Switzerland. The Agreement on Agriculture (AoA) under WTO requires clear understanding. It is an international organization designed to supervise and liberalize international trade. The WTO has 153 members, which represents more than 95% of total world trade. WTO cooperate closely with 2 other component IMF and World Bank. The WTO has 164 members and 25 observer governments. Liberia became the 163rd member on 14 July 2016, and Afghanistan became the 164th member on 29 July 2016.

WTO is a global organization to promote the multilateral trade and had played a pivotal role in facilitating the international trade after it came into force on January 1, 1995. However, it has got stuck in the market access initiative, as market access remains unaddressed due to stalemate of Doha round of talks.

FUNCTIONS OF WTO

1) Monitoring national trade policies.
2) Technical assistance and training for developing countries.
3) Cooperation with other international organizations.
4) The WTO is also a center of economic research and analysis.
5) Administering WTO trade agreements.
6) Forum for trade negotiations.
7) Handling trade disputes.

PURPOSE OF WORLD TRADE ORGANIZATION

- WTO is to ensure that global trade commences smoothly, freely and predictably.
- Transparency in trade policies.
- Work as an economic research and analysis center.

AIM OF WORLD TRADE ORGANIZATION

To create economic peace and stability in the world through a multilateral system based on consenting member states, that have ratified the rules of the WTO in their individual countries as well.

IMPACT OF WTO ON AGRICULTURAL ECONOMICS

The WTO has significantly influenced agricultural economics by promoting market access, reducing trade barriers, encouraging fair competition among countries. It has increased global agricultural trade and improved access to international markets. **(ii)**

WTO AGREETMENT ON AGRICULTURE

Agreement on Agriculture (AoA) under WTO The provisions under AoA can be understood to consist of five broad groups:

1. Market Access Commitment
2. Reduction Commitment for Aggregate Measure of Support (AMS)
3. Reduction Commitment for Export Subsidy
4. Sanitary and Phyto-Sanitary Measures (SPS)
5. Trade Related intellectual Property Rights (TRIPS)

(i) Market Access:

This includes tariffication, tariff reduction and access opportunities (Tariffication means that all non-tariff barriers such as).

Quotas, variable levies, minimum import prices, discretionary licensing, state trading measures.

(a) Tariffication of all non-tariff barriers (like converting quantitative restrictions to import duty)

(b) Reduction of all tariffs in a time bound framework

(c) If imports of foreign goods to the domestic market is less than three per cent in the base period (1986-88), it must be brought to three per cent and to further raise it to five per cent in the implementation period.

(d) If dumping is proved, the countries will have the freedom to increase the import duty.

(ii) Aggregate Measures of Support (AMS):

The aggregate measures of support for a country's agriculture are the sum of product specific and non-product specific subsidies. If AMS in the base period (1986-88) is more than 15 the permissible limit.

Export Subsidies

Under WTO Export subsidies deal with reduction on total budgetary support on export subsidies and reduction in the total quantity of exports covered by subsidy.

These are direct subsidies given by Governments given in cash or in kind to producers of the agriculture products against export performance and export of non- commercial agriculture products.

The reduction commitment for export subsidies requires that

(a) the developed countries would reduce it by 36 per cent in six years; and

(b) the developing countries would reduce it by 24 per cent in 10 years.

(iv) Sanitary and Phyto-Sanitary Measures (SPS)

The SPS provisions of AoA require all exporters to employ international standards relating to sanitary and phyto-sanitary conditions. In the case of default, the importing countries are allowed to prohibit imports from defaulting countries.

(v) TRIPS

Trade related intellectual property rights include copyrights, trade-marks, geographic indications, industrial designs, and patents. According to AoA, all the countries are required to provide for arrangements for protection of plant varieties. The developing countries were given a period of five years to evolve such arrangements.

The main features of the WTO Agreement on Agriculture (AoA), which are of concern to India, are:

(i) India has been maintaining quantitative restrictions (QRs) on import of 825 agricultural products as on 1st April, 1997. Under the provisions of the Agreement, such QRs were to be eliminated. India had sought to remove them in three phrases within an overall time frame of six years i.e. upto 31st March, 2001. These QRs have since been replaced with appropriate tariffs.

(ii) The Agreement also imposed constraints on the level of domestic support provided to the agricultural sector. In India's case, it may have, in future, some implications on minimum support prices given to farmers and on the subsidies given on agricultural inputs. However, the Agreement allows us to provide domestic support to the extent of 10% of the total value of agricultural produce. Our support to the Indian farmers continues to be less than permissible limit.

(iii) Disciplines on export subsidy do not affect us as India is not providing any export subsidy on agricultural products.

(iv) The Agreement allows unlimited support to activities such as:

(a) Research, pests & diseases control, training, extension and advisory services;

(b) Public stock holding for food security purposes;

(c) Domestic food aid; and

(d) Income insurance and food needs, relief from natural disasters and payments under the environmental assistance programmes.

WTO IMPACT ON AGRICULTURE AND FOOD SECURITY

India's agriculture policies aimed at improving its food security have received increased scrutiny by developed countries.

Issues with India's Food Security Regime as claimed by Developed countries.

India provides MSPs to its farmer. (Big corporate unable to get profit)

India also buys the produce from its farmers. (Protects farmers from the clutches of big corporates. With the help of PDS India distributes subsidized food grains. (Big corporates deprived of its potential customers). Due to NFSA, government holds control over Agriculture. (Prevent big corporates from assuming central role).

CHALLENGES FACING BY AGRICULTURAL TRADE IN WTO

Challenges include addressing non-tariff barriers sanitary and phytosanitary measures.

ensuring fair and equitable agricultural subsidies.

balancing the interests of developed and developing countries.

SANITARY AND PHYTOSANITARY (SPS) MEASURES

These are the conditions imposed on the agricultural goods to adhere the norms of sanitation, hygiene, use of Child Labour before exporting products to other countries. India has demanded transparent, uniform, non-discriminatory SPS.

The following three dimensions of sustainable and equitable Agriculture Policy are threatened by the WTO induced Globalization process.

Ecological security

Livelihood security

Food security.

DENIAL TO MARKET ACCESS

Developed countries high domestic support, export subsidies, and denial of market access through various tariff and non - tariff barriers has presented many challenges to India.

ROLE OF GOVERNMENT IN PROMOTING AGRICULTURAL TRADE IN WTO

Governments play a crucial role in creating a supportive environment for agricultural trade by implementing effective policies, providing necessary infrastructure, supporting farmers' capacity building and ensuring compliance with international standards.

CONCLUSIONS

The WTO has had a significant impact on agricultural economics, but there is room for improvement. Policy makers should strive for fair and inclusive trade agreements, sustainable agricultural practices, and policies that prioritize the well-being of farmers and food security for all.

It will be "just" to highlight one issue each where the RICH countries and poor countries need to be honest. Let us be honest to understand that dominance of politics over economics and fair play will never render justice.

"With malice toward none, charity for all with firmness in right as god has given us to see the right, let us strive on to achieve adjust and prosperous nation among all other nation".

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RECENT ADVANCES IN CLIMATE CHANGE ADAPTATION TECHNIQUES

Abstract
Climate change adaptation involves strategies and technologies that reduce vulnerability to climate impacts. Emerging climate technologies play a vital role in mitigating climatic hazards and aid in adaptation efforts. Artificial Intelligence (AI) improves predictive capabilities and decision-making in agriculture and disaster response. Renewable energy, electric vehicles, and green hydrogen contribute to resilient, low-emission systems. Climate-smart agriculture, carbon capture, and low-carbon technologies strengthen environmental and food system resilience. Despite these advancements, key challenges, including limited financing for adaptation implementation, high implementation costs, and poor alignment with business strategies, hamper the beneficial effects. Addressing these barriers is essential to scale and mainstream climate-tech solutions for effective global adaptation.
Keywords: Drones, Carbon capture, AI, EV, CSA, Green hydrogen.

Introduction
The term climate change adaptation describes actions that are capable of reducing the effects of climate change pertaining to extreme weather patterns and events, rising sea levels, depletion of biodiversity, and issues relating to water and food scarcity.

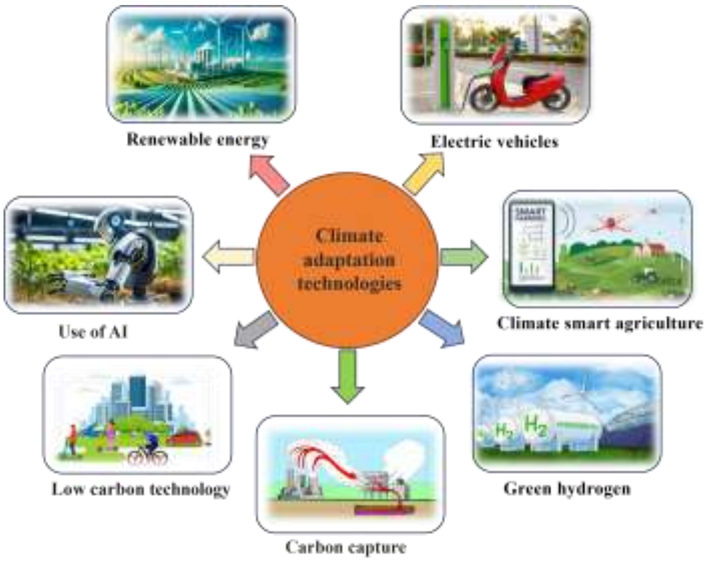

Figure 1. Climate technologies aiding adaptation efforts

These actions can be undertaken at the local level, such as growing drought-resistant crops, conserving water, and improving agronomic practices, but can also be undertaken at the national and global levels through policies, effective early warning systems, and investing in infrastructure that can withstand more severe weather and events. Climate change impacts are felt through all levels, and by working together and collectively at the national and global levels, we can identify ways to sustain food security in the face of a changing climate.

Climate change technologies aiding adaptation strategies

Climate technologies including renewable energy, electric mobility, AI-based forecasting, climate smart agriculture, and carbon capture technologies form an integral part of climate change adaptation strategies (Fig. 1). They reduce emissions, improve resilience to climate change impacts, support sustainable development and support communities in developing the knowledge, resources, and infrastructure needed to prepare for and respond to the impacts of climate hazards.

1. Use of Artificial Intelligence (AI): AI is transforming agriculture by optimizing water use, crop rotation, pest control, nutrient management, and boosting productivity. It also enhances agrometeorology operations through advanced weather forecasting using drones and remote sensing techniques, enabling precise and data-driven farming practices (Zougmore et al., 2021).

***AI weather predictions*:** Farm planning is often impacted by weather predictions, but climate change and pollution have created changing or unpredictable seasonal patterns. AI-powered weather forecasting offers a crucial solution by combining real-time satellite data, historical records, and machine learning to deliver accurate, localized predictions. State-of-the-art AI systems utilize big data to evaluate the likelihood of variables such as rain, temperature, humidity, and climate disasters. This climatic data aids farmers in deciding the optimal time to plant, irrigate, and fertilize their crops. This precise information reduces risks, prevents crop losses, and enhances yields, making agriculture more resilient. By integrating weather data, AI models forecast pest outbreaks and diseases, enabling precise pesticide use that protects soil quality and boosts productivity (Naranammal and Priya, 2024).

***AI-based soil and crop health monitoring system*:** Poor soil health can greatly affect the quality and quantity (yield) of crops. Using AI and enhanced versions of monitoring will help to assess and improve our understanding of soil nutrients, pH, moisture, and texture using data collected from sensors, drones and satellites. The use of AI-powered drones for monitoring crop health significantly reduces the time and labour required for field inspections while improving accuracy and efficiency. Drones can identify moisture stress, pest damage, and nutrient deficiencies in plants and soils. By giving real-time data and actionable information, AI-powered drones help farmers in better decision-making and improve overall agricultural productivity (Chinchorkar, 2025).

***AI robotics in agriculture*:** Robotics and AI have revolutionized farming by automating manual tasks with precision and efficiency. AI-powered robots equipped with sensors and machine learning autonomously navigate fields to perform activities like crop harvesting (Soussi et al., 2024). They can handle delicate crops like strawberries without damage, improving quality and speed. This technology reduces physical strain on workers, promoting a safer and more sustainable farming environment.

2. Renewable energy: Agrivoltaics integrates solar energy with agriculture, addressing rural challenges by boosting crop yields, conserving water, providing sustainable income, and reducing chemical use (Mahto et al., 2021). It offers financial relief in regions with high farmer distress and promotes local solar panel manufacturing, creating jobs and supporting India's economy. Renewable energy is central to climate change mitigation and adaptation, with 34% of countries including it in their Nationally Determined Contributions by 2020. India, despite missing its 2022 target of 175 GW, achieved 120 GW of renewable capacity and aims for 500 GW non-fossil fuel capacity by 2030. Solar and wind energy attract growing investments due to their sustainable returns. Solar photovoltaics is the fastest-growing sector and benefits from government incentives like the production-linked incentive scheme. By 2025, India plans to add 29 GW of solar cell and 33 GW of module manufacturing capacity, becoming a global renewable energy leader.

3. Electric vehicles: Electric vehicles not only reduce greenhouse gas emissions but also help build a resilient, sustainable transport infrastructure. India's EV market is growing, particularly in three-wheelers, which account for 53% of sales. However, EV adoption in two and four-wheelers remains low at 5% and 1% respectively. Key challenges include expanding charging infrastructure and lowering battery costs. The government's FAME scheme deployed 862 electric and hybrid buses by 2021 and is now focused on nationwide charging infrastructure expansion. The production-linked incentive scheme aims to boost domestic manufacturing of advanced chemistry cells to reduce battery costs. The private sector is also contributing, with companies deploying EV fleets and installing charging stations on highways. These initiatives are paving the way for a low-emission, climate-resilient transportation system in India.

4. Climate-smart agriculture (CSA): CSA is helping Indian farmers adapt to climate change through innovative practices like soilless farming, bioengineered crops, and precision agriculture. Tools such as satellite imagery and drones enable efficient use of water, fertilizers, and pesticides (Juhola et al., 2017). In drought-prone Maharashtra, farmers are adopting greenhouses, growing less water-intensive crops, and using cross-breeding for resilience. Over 1,300 agri-tech startups, mainly in Karnataka, Maharashtra, and Delhi-NCR, use AI, IoT, and machine learning to offer real-time, data-driven solutions. The government's agriculture accelerator fund further supports these innovations, driving a shift toward sustainable and climate-resilient agriculture.

5. Green hydrogen: It is produced using renewable energy, offers a clean alternative to fossil fuels. India's national green hydrogen mission aims to build 5 million metric tonnes of green hydrogen capacity annually, supported by 125 GW of renewables. The mission includes green hydrogen hubs, incentives for electrolysis manufacturing, and focuses on sectors like steel, transport, and energy storage to cut emissions. Replacing natural gas-based hydrogen in fertilizers and petrochemicals, green hydrogen reduces import dependence. Hydrogen fuel cell vehicles also avoid reliance on imported raw materials. With proper infrastructure, India aims for self-reliance in the hydrogen supply chain and a sustainable energy future.

6. Carbon capture: It is mainly a mitigation tool and also supports climate adaptation through co-benefits. The global market for carbon capture, utilization, and storage (CCUS) is growing, with investments rising over the past two years. In India, industrial-scale carbon capture is limited by high costs, but startups enabling carbon credits for nature-based solutions have raised around USD 11 million. Direct air capture, which extracts CO_2 from the atmosphere, is emerging but faces challenges in cost and scalability. Broader CCUS adoption requires strong policy support, including tax benefits, subsidies, and loan guarantees. Captured CO_2 can contribute to a circular economy, being converted into polymers for products like laptop packaging. However, CO_2 utilization technologies lag behind capture methods, necessitating increased investment in research and development to drive innovation (Mangat & Kaundal, 2025).

7. Low carbon technologies: These technologies aim to minimize carbon dioxide and other harmful emissions to help combat climate change by promoting cleaner, more sustainable energy production, transportation, and industrial activities. These methods improve soil health, increase carbon sequestration, and improve resource efficiency, supporting climate-resilient and environmentally friendly food systems. Some of the major carbon-negative technologies are shown in Fig. 2.

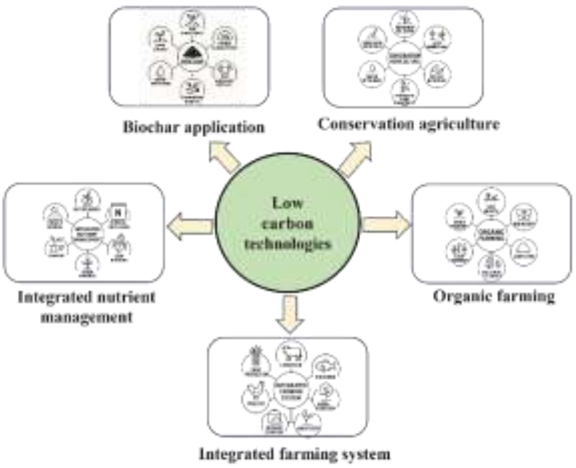

Figure 2. Low-carbon technologies aiding adaptation efforts

Integrated nutrient management: This approach enhances nutrient management by integrating organic inputs such as compost and green manure, which contribute to the buildup of soil organic carbon. Decreasing dependence on synthetic nitrogen fertilizers also helps reduce nitrous oxide emissions. Additionally, agricultural practices like intercropping, mixed cropping, crop rotation, and the inclusion of leguminous nitrogen-fixing crops improve both nutrient and water use efficiency, promoting more sustainable and resilient farming systems.

Biochar application: Applying biochar enhances soil biological activity, increases nutrient use efficiency, and promotes carbon sequestration. When combined with nitrogen fertilizer, biochar helps regulate the mineralization of organic nitrogen. Furthermore, biochar modifies carbon pool ratios, contributing to a reduction in greenhouse gas emissions.

Conservation agriculture (CA): CA practices such as minimum tillage, residue management, and crop diversification protect soil from erosion, minimize evaporation, and preserve nutrients. CA also reduces CO_2 emissions from mechanized operations by decreasing energy requirements. Additionally, it promotes water and nutrient conservation, enhances crop productivity and efficiency, and strengthens soil ecosystem resilience while boosting organic carbon sequestration.

Organic farming / Integrated farming system (IFS): These systems emphasize crop rotation, mulching, composting, and the use of green manures instead of inorganic fertilizers, thereby promoting the replenishment of soil carbon (Srinivasa Rao et al., 2024). IFS combines crops, livestock, aquaculture, and agro-industry to recycle resources and enhance soil organic carbon. It improves productivity, reduces risks and external inputs, optimizes organic resource use, lowers fertilizer and pesticide reliance, conserves farm resources, and ensures stable income while maintaining agro-ecological balance.

Constraints in technology adaptation

Mitigation takes precedence over adaptation in finance flows. Mitigation actions are seen as having more direct and measurable outcomes compared to adaptation efforts. For example, reducing carbon emissions offers a clear metric to evaluate mitigation effectiveness, whereas the impact of community-based flood resilience programs is harder to quantify. As a result, international funding has predominantly prioritized mitigation. Many businesses treat adaptation as a corporate social responsibility rather than a core business necessity. This mindset needs to shift. Companies must recognize that climate change presents real risks to their operations and supply chains and align climate adaptation strategies with their overall business goals. Technologies aimed at improving resilience often involve significant implementation costs. Continuous research and development are necessary to make these innovative technologies more affordable and scalable. Additionally, scaling adaptation measures is challenging because effective solutions are not universally applicable and must be tailored to specific local contexts.

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CANINE ATOPIC DERMATITIS- ITS ASSOCIATED RISK FACTORS AND TREATMENT

Abstract:
Canine atopic dermatitis (CAD) is a common, multi-factorial, pruritic, and inflammatory skin condition that results from complicated interactions amongst genetic, environmental, microbial, and immunological elements. It's a Type-I hypersensitive reaction to allergens within the environment, and it's characterised by means of itching, redness, and recurrent secondary infections. This assessment summarises what we know so far, approximately the reasons, improvement, signs and symptoms, and treatments for CAD, with a focal point on recent advances in focused immunotherapy. To make accurate multi-modal control plans for a dog that might be affected, you want to understand how these mechanisms work.
Keywords: Canine atopic dermatitis, hypersensitivity, allergens, immunotherapy.

Introduction:
Canine atopic dermatitis (CAD), additionally known as atopy or allergic inhalant dermatitis, is one of the most common allergic and skin diseases in dogs. An aggregate of genetic and environmental elements causes it. The global committee on allergic illnesses of animals (ICADA, 2023) defines CAD as a hereditary, frequently pruritic, and predominantly T-cell-mediated inflammatory reaction and skin disease arising from the interplay of skin barrier dysfunction, allergen sensitisation, and microbial dysbiosis. Dog that might be affected regularly have chronic itching, redness, and repeated cases of otitis externa or pyoderma, which substantially lowers their quality of life.

Causes:

Environmental factors:
CAD is mainly as a result of allergens in the environment. Some of the most common allergens are dust mites inside the domestic, mould, and pollen from weeds, grasses, and trees. People think that residence dust mites are the main cause in manifesting these issues. There are also a whole lot of chemicals made by means of people that may harm the epithelial barrier in dogs nowadays. These chemicals include detergents, surfactants, and microplastics. As an example, sodium lauryl sulfate, which is in lots of shampoos and cleaning products for the home, breaks down the pores and skin barrier and modifies the balance of microbes.

Dietary Factors:

The diet and gut microbiome are very important for keeping the immune system and skin healthy. A Western diet rich in trans-fatty acids is associated with an accelerated chance of atopic diseases. Conversely, diets more in n-3-polyunsaturated fatty acids and early exposure to diverse microbiota might also aid in the prevention of allergic illnesses by fostering immune tolerance. Dietary modifications that affect the gut-skin axis could be a new way to deal with CAD.

Genetic Factors:

Genetic predisposition plays an essential role in the advancement of CAD. There are positive breeds which can be more likely to have the condition everywhere globally. Those include Boxers, Bulldogs, Labrador Retrievers, Pugs, and West Highland White Terriers. The disorder phenotype may also vary by region, suggesting gene-surroundings interactions.

Microbial Factors:

The microbiota of skin may be very vital for retaining it healthy. Dog with CAD frequently have dysbiosis, which is an imbalance in the types of microbes in their bodies. There are fewer types of microbes and greater harmful ones, which includes *Staphylococcus pseudintermedius* and *Malassezia pachydermatis.*These organisms make itching and infection worse. Some things that make the balance of microbes even worse are high humidity, changes in pH, and using antibiotics too frequently keeps the skin more infectious.

Pathogenesis:

CAD takes place whilst the immune system reacts badly to things in the environment that cause allergic reactions. Whilst the frame first comes into touch with an allergen, it activates antigen-providing cells, which then prompt T-helper 2 (Th2) cells. Then, those cells let out cytokines like IL-4, IL-5, and IL-13, which assist B cells in growing and making IgE. Whilst IgE binds to mast cells, they release histamine and different chemical substances that make you itch and swell up when they come into contact with the allergen once more. Persistent infection harms the skin barrier, which could allow extra allergens in and let the microbes grow, which maintains the cycle.

Clinical signs:

CAD generally commences between six months to three years of age, despite the fact that it may occur as overdue as seven years. The maximum essential medical sign is persistent pruritus. Erythema, alopecia, lichenification, and hyperpigmentation are some other common signs. Maximum of the time, lesions show up at the face, ears, forelimbs, groin, and lower abdomen. Secondary bacterial or fungal infections, especially pyoderma and Malassezia dermatitis, frequently exacerbate the situation.

Treatment:

Corticosteroids :

Corticosteroids applied to the skin and taken by mouth are still the preferred way to treat acute CAD. Topical sprays like 0.015% triamcinolone acetonide work properly for lesions that are most effective in a single place. For severe or substantial instances, short term usage of oral prednisolone, prednisone, or methylprednisolone are effective. Long-term use must be avoided to lessen negative consequences.

Cyclosporine:

Cyclosporine is a calcineurin inhibitor that prevents the production of IL-2, which lowers the activation of T-cells. It has outcomes on the immune system and reduces infection. Each of the modified methods and the liquid form is well-tolerated and works well for long-term control.

Oclacitinib:

Oclacitinib is a Janus kinase (JAK) inhibitor that works mostly on JAK1. It stops cytokine signalling, which makes you itch and swell up. For two weeks, you ought to take 0.4-0.6 mg/kg by means of mouth two times a day, and then once a day for preservation. It works in addition to cyclosporine and speeds up the stoppage of itching.

Lokivetmab:

Lokivetmab is a monoclonal antibody that specifically focuses on interleukin-31 (IL-31), a cytokine that causes itching. Once you have shots as soon as every month, many puppies experience loads better and feature longer durations of remission. However, IL-31 isn't always the handiest thing that can cause CAD, so some puppies may additionally nevertheless have flare-ups that are caused by other things.

Pentoxifylline:

Pentoxifylline is a methylxanthine derivative that changes the immune system by converting how leukocytes and platelets work. You're taking it by means of mouth every eight to twelve hours in doses of 20 to 30 mg per kg. Aspect outcomes are rare, but it can take up to a few months for the clinical reaction to happen. Contemporary evidence shows constrained efficacy, and it is commonly considered adjunctive therapy.

Conclusion:

It is nonetheless hard to deal with dog atopic dermatitis because of many factors, such as genetics, the immune system, and the environment. The use of oclacitinib and lokivetmab in targeted remedy has modified how diseases are dealt with. But to manipulate it nicely, you typically want a multimodal approach that includes controlling the surroundings, restoring the skin barrier, improving the microbiome, and immunotherapy. Persevering studies into the pathogenesis of CAD will enhance diagnostic precision and therapeutic effects in affected dogs.

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UNDERSTANDING MARKET LINKAGES IN APPLE EXPORT SUPPLY CHAINS

Abstract

Apple cultivation is a vital component of the horticultural economy in Hilly regions of India like Himanchal Pradesh, Uttarakhand, Jammu Kashmir and Ladakh, contributing significantly to Grower's livelihoods and the state's agricultural output. However, growers across the region face a range of persistent challenges that hinder productivity and profitability. The apple export supply chain represents a complex network connecting producers, aggregators, processors, exporters, and international markets. Understanding market linkages within this network is critical to enhancing the efficiency, profitability, and sustainability of the apple industry. This article examines the structure and dynamics of apple export supply chains, with a focus on identifying key stakeholders, value addition points, and marketing constraints. The study highlights issues such as fragmented market access, inadequate cold chain infrastructure, quality deterioration during transit, and limited integration between farmers and exporters. It also explores how digital platforms, contract farming, and cooperative marketing models can strengthen linkages and improve transparency in price discovery. By analyzing existing challenges and opportunities, the article aims to provide insights into optimizing market connections, reducing post-harvest losses, and improving the global competitiveness of apple exports. Strengthening these linkages is essential for ensuring better returns to growers, sustainable export growth, and long-term resilience in the horticultural supply chain.

Keywords: Apple Supply Chain, Market Linkages, Export Marketing, Value Chain Integration, Post-Harvest Management.

Introduction: Apples are among the most valuable temperate fruit crops cultivated in India, primarily in states such as Jammu & Kashmir, Himachal Pradesh, and Uttarakhand. With increasing global demand for high-quality fruits, apple exports have become an important avenue for income generation and rural development. However, the supply chain for apple exports is multi-layered and often faces inefficiencies due to fragmented market structures, inadequate infrastructure, and weak coordination among stakeholders. Strengthening market linkages is, therefore, crucial to bridge the gap between production and international markets.

Structure of the Apple Export Supply Chain: The structure of the apple export supply chain is a multi-stage process that begins at the orchard and ends at international consumer markets. It involves a coordinated flow of products, information, and finances among multiple stakeholders, including farmers, traders, processors, exporters, and distributors. The first stage is production and harvesting, where apples are cultivated and harvested at optimal maturity to maintain quality and shelf life. After harvesting, the fruits are transported to aggregation centers or local mandis, where they undergo grading and sorting based on size, color, and quality parameters suitable for export. Proper packaging at this stage is crucial to prevent mechanical injury and ensure uniformity as per international standards. The next critical step involves cold storage and transportation, which play a vital role in maintaining the freshness and quality of apples during transit. Efficient cold chain systems—comprising pre-cooling units, refrigerated vehicles, and controlled-atmosphere storage—help reduce post-harvest losses and preserve export quality. The processing and packaging stage follows, where apples are cleaned, waxed, and packed in standardized cartons or crates with proper labeling, ensuring traceability and compliance with international phytosanitary regulations. Subsequently, the fruits move to exporters or export houses, which handle documentation, quality certification, and logistics for overseas shipping. These exporters coordinate with government agencies for quarantine clearance and export licensing. Finally, apples reach foreign distributors, wholesalers, and retailers, where they are marketed to consumers. Each stage in this supply chain is interdependent, and inefficiencies at any level—such as poor handling, delayed transportation, or inadequate storage—can significantly affect the quality and market value of the fruit. Therefore, a well-integrated and transparent supply chain system is essential to ensure competitiveness, profitability, and sustainability in apple exports.

Importance of Market Linkages: Importance of Market Linkages

Market linkages play a crucial role in connecting producers with markets, ensuring that agricultural products like apples move efficiently from farms to consumers while maximizing value for all stakeholders involved. In the context of apple exports, strong market linkages facilitate smooth coordination between farmers, traders, processors, exporters, and buyers, enabling better communication, planning, and resource utilization. Effective linkages help farmers access reliable markets, obtain fair prices, and reduce dependency on intermediaries who often capture a large share of profits. They also ensure timely flow of market information related to demand, prices, and quality requirements, allowing producers to make informed decisions about harvesting, grading, and packaging. Moreover, robust market linkages encourage **value addition** through improved post-harvest handling, processing, and packaging practices that meet international standards. This not only enhances product competitiveness but also opens up opportunities for farmers to participate in export markets. Through **collective marketing models**, such as Farmer Producer Organizations (FPOs) or cooperatives, smallholder farmers can achieve economies of scale, negotiate better prices, and strengthen their bargaining power in the supply chain.

Moreover, from an economic perspective, efficient market linkages help minimize post-harvest losses and logistical inefficiencies, leading to higher profitability and sustainability of the supply chain.

They also promote **transparency and trust** among stakeholders by ensuring fair trade practices and traceability of produce. In the long term, strong linkages contribute to rural development by improving farmer incomes, generating employment, and encouraging investment in infrastructure and technology. Thus, understanding and strengthening market linkages is essential for building a resilient and inclusive apple export supply chain that benefits producers and ensures consistent quality for global consumers.

Fig: Market Chain of Apple from Producer to Consumers.

Challenges in Apple Export Supply Chains:
Challenges in Apple Export Supply Chains

The apple export supply chain faces numerous challenges that affect its efficiency, profitability, and sustainability. One of the major issues is **fragmented marketing channels**, where smallholder farmers rely heavily on intermediaries such as commission agents and wholesalers to sell their produce. This multi-layered marketing system often results in reduced profit margins for growers and limited transparency in price determination. Another significant challenge is the **inadequate cold chain infrastructure**, which includes insufficient pre-cooling units, cold storages, and refrigerated transport. The lack of proper temperature management leads to high post-harvest losses, quality deterioration, and reduced export potential. **Quality control and standardization** also pose major hurdles in the apple export sector. Many farmers are unaware of international grading, packaging, and phytosanitary requirements, leading to the rejection of consignments or lower export prices. In addition, **price volatility** caused by fluctuating domestic and international demand, currency exchange rates, and market uncertainties adds risk to the supply chain. Limited access to **market information systems** further prevents farmers from understanding current export trends, buyer requirements, and emerging opportunities in global markets. Another challenge lies in **weak institutional and policy support**. The lack of effective coordination among government agencies, exporters, and producer organizations hinders smooth export operations. Delays in obtaining certifications, clearances, and logistical bottlenecks at ports often increase transaction costs. Moreover, **inadequate financial access** and limited insurance coverage make it difficult for small and medium farmers to invest in quality inputs, infrastructure, and post-harvest technologies.

Lastly, **climate variability** and unpredictable weather conditions affect apple yield, quality, and timing of supply, creating further instability in export planning. Addressing these challenges requires a comprehensive approach involving investment in infrastructure, policy reforms, capacity building, and digital solutions to build an efficient and resilient apple export supply chain.

Strategies to Strengthen Market Linkages:
Strategies to Strengthen Market Linkages

Strengthening market linkages in the apple export supply chain is essential for improving efficiency, enhancing farmer income, and ensuring global competitiveness. A well-connected marketing network not only reduces transaction costs but also improves coordination between producers, traders, and exporters. One of the most effective strategies is the **formation of Farmer Producer Organizations (FPOs)** or cooperatives. These collective structures enable smallholder farmers to pool resources, aggregate produce, and negotiate better prices with buyers. FPOs also facilitate access to inputs, credit, and market information, helping farmers become more market-oriented and professional.

Contract farming is another key approach that can directly link farmers with exporters or processors. This system provides assured markets, price stability, and technical support while ensuring that buyers receive consistent quality produce. Alongside this, **investment in cold chain infrastructure**—including pre-cooling facilities, refrigerated transport, and modern packhouses—is vital for reducing post-harvest losses and maintaining the quality required for international markets.

The adoption of **digital marketing platforms and e-marketplaces** can further revolutionize apple marketing by enabling farmers to connect directly with buyers, track market trends, and access real-time price information. These digital systems also promote transparency and traceability, which are critical for export certification and consumer confidence. Capacity building and **training programs** should be organized to educate farmers on grading, packaging, quality standards, and export documentation. Strengthening **public–private partnerships (PPPs)** can attract investment, enhance logistics, and improve value addition in the supply chain. Additionally, **policy support and financial incentives** from the government can encourage innovation and participation in export-oriented production. Together, these strategies can create a more integrated, transparent, and resilient apple supply chain—ensuring fair returns to farmers, reducing post-harvest losses, and boosting India's position in the global apple export market.

Conclusion:- Understanding market linkages in apple export supply chains is vital for the sustainable development of the horticulture sector. By strengthening coordination among stakeholders, improving infrastructure, and promoting technology-driven marketing systems, India can significantly enhance its share in the global apple trade. Empowering farmers through better linkages not only ensures fair returns but also contributes to the overall growth and resilience of the agricultural economy.

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INTEGRATING MICROALGAE AND BACTERIA FOR WASTE WATER TREATMENT

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Abstract

Punjab, an agrarian state of India, relies heavily on groundwater for irrigation. However, it is now facing water scarcity due to pollutants present in its water resources. Recycling wastewater from sewage treatment plants (STP) and village ponds is essential to minimize water scarcity. Microalgae based waste water treatment system offers a sustainable cost-effective alternative that does not require arable land and enables nutrient recovery. Microalgae can efficiently remove nitrogen, phosphorus, heavy metals, and organic matter while producing biomass for biofuels, animal feed, and high-value bioproducts. When integrated, a microalgae bacteria consortium can achieve high nutrient removal efficiency, lowering operating costs and significantly reduce sludge generation. This approach aligns with circular economy providing both lowering water stress condition and resource recovery, thus offering a viable solution for sustainable wastewater treatment in water scarce region like Punjab.

Introduction

Water is an essential natural resource for industrial activities, life support, and the sustainable growth of agriculture. Punjab state of India often referred to as the "Granary of India," has played a crucial role in ensuring food. Punjab is an agrarian state that makes up 1.57% of India's total land area. Almost 85% of the land is under cultivation, with cropping intensity surpassing 198%. Most of the crops in Punjab are irrigated using groundwater. Punjab is a region which faces high to extremely high levels of water scarcity (India Water Tool., 2024). Punjab's groundwater is rapidly running out; as of 2020, withdrawals exceeded recharge by 164% (CGWB., 2022), compared to 100% in 2009 (Rodell et al., 2009). Punjab's declining groundwater level is endangering environmental sustainability by drying up the forest ecology, eliminating wetlands, lowering base flow to rivers, deteriorating water quality, and lowering soil moisture. High concentration of several pollutants, such as salinity, fluoride, arsenic, nitrate, sulphate, and iron, are indicative of decline in water quality. In a recent study, hazardous metals such as arsenic, boron, cadmium, lithium, manganese, lead, strontium, and selenium were found in groundwater in the semi-arid southwest region of Punjab. Furthermore, nitrate concentrations in the examined samples exceeded the permissible limits (Singh et al.,2025).

Hence, it is essential to recycle and utilize wastewater produced by wastewater treatment plants (STP) and village ponds in order to alleviate Punjab's alarming pace of water drop. The majority of developing countries employ only use secondary levels of wastewater treatment, which is ineffective at removing nutrients from wastewater. Therefore, to ensure effective wastewater management and achieve nutrient removal within permissible limit, there is need to adopt alternative approaches such as microalgae and their bacterial consortium. This system offers sustainable cost-effective, economical and does not require arable land for cultivation..

Why Microalgae?

Microalgae are the organisms that have the ability to conduct photosynthesis. These can be autotrophic and heterotrophic, depending upon the species and growth conditions. Microalgae can be found in a variety of aquatic environments such as lakes, ponds, rivers, oceans, and even wastewater (Baroukhet al., 2015). By using sunlight, carbon dioxide, and other nutrients, microalgae have the ability to remove nutrients, organic and inorganic substances, heavy metals and other impurities present in wastewater. In wastewater, microalgae may absorb ammonia (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), and simple organic nitrogen compounds such as urea and amino acids to produce proteins, nucleic acids, and phospholipids, thereby reducing the nutrient load that causes eutrophication in receiving waters. The fact that microalgae use comparatively few resources is a major benefit. They can be grown on non-arable ground with wastewater or salty water, which lessens competition with food crops and uses less freshwater. Additionally, microalgae actively participate in carbon capture by using CO_2 during photosynthesis and making it possible to integrate with industrial carbon capture systems to reduce greenhouse gas emissions (Daneshvar et al.,2022). Nowadays, the use of microalgae to stabilize trash is gaining popularity around the world.

Microalgal populations accumulate biomass rich in lipids, carbohydrates, proteins, necessary amino acids, and high-value metabolic components. In addition to protein, microalgae are high in vitamins, minerals, and bioactive substances, which improves their nutritional value and health advantages. Microalgae biomass serves as a valuable source of carbon compounds for the production of vitamins, bioactive chemicals, and biofuels (Khan et al., 2018). Microalgae are a remarkable substitute because of their high protein content, quick growth rates, and ability to flourish in nutrient-rich wastewater systems and non-arable soil. Additionally, microalgal biomass provides cost-effective value through co-products including pigments for cosmetics, lipids for biofuels, and antioxidants for nutraceuticals, promoting a multi-product biorefinery strategy in line with the ideas of the circular economy (Samoraj et al., 2024).

Concept of using Microalgae-bacteria consortium

This concept of algal-bacteria consortium was initially proposed in 1981 by Nambiar and Bokil.In the wastewater treatment process, the microalgal-bacterial consortium engages in a symbiotic relationship that involves the exchange of O_2, CO_2, and NH_4^+ ions. The bacteria oxidize organic carbon molecules found in wastewater sources and transform them into CO_2. These algae subsequently respired the CO_2 that the bacteria had created in order to perform photosynthesis and convert it into algal cell materials (Chang et al.,2017). Using light-driven photosynthesis, microalgae produce oxygen for the bacteria and encourage nitrification during the day. At night or in low oxygen environments, denitrifying bacteria convert nitrate and nitrite into nitrogen gas (N_2), completing the nitrogen removal process. Most microalgae, including *Chlorella vulgaris* and *Scenedesmus obliquus*, prefer ammonium as a nitrogen source and can directly absorb it for growth and protein synthesis, this mineralization step is crucial (Li et al.,2024). Simultaneously, nitrifying bacteria convert ammonium into nitrite (NO_2^-) and nitrate (NO_3^-), which are also sources of nitrogen for microalgae but require more energy to assimilate. Microalgae and a water denitrification process can also work together to boost nitrate removal efficiency through a synergistic effect and supply the necessary electron donor for denitrifies. As biomass growth increases, the symbiotic interaction of microalgae and bacteria enhances the removal efficiency of nutrients from wastewater sources. Apart from its utilization for detoxifying organic and inorganic pollutant from wastewater sources, it can recover resources for bioeconomy of both high- and low-value products (i.e. fertilizers, algal-based plastics and fibres and aquaculture feed) (Khoo et al., 2021).This integrated method produces a strong, self-sustaining wastewater treatment process that may achieve high nutrient removal efficiency while lowering operating costs and minimizing the generation of sludge.

Fig.1. Symbiosis interaction between microalgal and bacteria in the wastewater treatment

There are reports of using microalgae and bacteria for treatment of different types of waste water:

Microalgae sp.	Bacterial sp.	Type of waste water	Overall nutrient removal efficiency	Reference
C. Vulgaris	bacteria profoundly found in the activated sludge process	Domestic wastewater	Ammonia, COD, BOD, and phosphate were around 88.96%, 89.02%, 94.85%, and 99.79%, respectively	Moondra et al.,2020
Scenedesmus and *Desmodesmus*	-	Potato wastewater	Totaldissolved nitrogen, total dissolved phosphorus, and demand, were found 59%, 32%, and 93%, respectively.	Yuan et al., 2021
Chlorella vulgaris (No. FACHB-8)	*Bacillus licheniformis* (No. 1.7461)	Municipal river in the Yangpu District of Shanghai, China	COD, TDP, TDN were 86.6% (175.8 mg L^{-1}), 80.3% (4.97 mg L^{-1}) and 88.9% (31.2 mg L^{-1}), respectively.	Ji et al., 2019
Chlorella sorokini ana strain DBWC2 & *Chlorella* sp. strain DBWC7	*Klebsiella pneumoniae* strain ORWB1 & *Acinetobacter calcoaceticus* strain ORWB3	Artificial wastewater and raw dairy wastewater	nitrate removal, COD removal efficiency was found to be 2.84 g L^{-1}, 93.59%, 82.27% and 2.87 g L^{-1}, 84.69%, 90.49% in artificial wastewater and raw dairy wastewater respectively.	Makut et al.,2019
C. pyrenoidosa	Nitrifying bacteria	Dairy wastewater	Around 95% ammonium nitrogen and soluble chemical oxygen demand (SCOD), around 99.67% and 90.25% of Nitrate nitrogen (NO_3^--N) and Phosphorus (PO_4^{3-}- P) removal were achieved	Das et al., 2022

Conclusion

The integration of microalgae–bacteria consortia offer an eco-friendly, cost-effective, and sustainable solution for wastewater treatment, achieving high nutrient removal while minimizing sludge production. This symbiotic system not only detoxifies pollutants but also enables resource recovery for value-added products, aligning with circular economy principles. Its ability to operate on non-arable land using wastewater makes it a promising approach for addressing water scarcity and environmental challenges.

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Anti-Nutritional Factors (ANFs) in Food Grain Crops, Health Impacts and Mitigation Strategies

Introduction:

In Asian countries, cereals and legumes are considered vital staple foods. Rice, wheat, and maize are still important staple food crops because of their extensive consumption. Cereal grains are rich in carbohydrates, proteins, vitamins, and other nutrients as well as dietary fiber, which is necessary for human health development and maintenance [1,2,3]. One of the major edible food crops, wheat, is consumed by around one-third of the world's population. Wheat, the most diverse grain, is grown all over the world and yields more than 750 million tonnes annually [4]. Due to its large composition, which includes macronutrients like proteins, carbohydrates, and lipids as well as minerals like zinc, phosphorus, iron, calcium, and magnesium, wheat is mainly regarded with high 'Nutritional Values' [1,5]. After rice and wheat, corn is thought to be the third most important cereal crop in the world [6]. Large swaths of the world, including America, Africa, and Asia, cultivate corn [7,8]. The anti-nutritional factors (ANF) are the toxic substances produced naturally in various plants, cause serious problems in human and animal nutrition. They reduce the nutrient utilization or food intake when consumed as foods [9]. The ANFs fall into two main categories: proteins (like lectins and protease inhibitors) that are sensitive to typical processing temperatures, and other substances that are stable or resistant to these temperatures, such as polyphenolic compounds (primarily condensed tannins), non-protein amino acids, and galactomannan gums, among many others [10]. Aletor (1993) states that there are a number of ANFs that are highly important in plants that are utilized as animal feed and human food. Haemaglutinnins (concanavalin A, ricin), plant enzymes (urease, lipoxygenase), cyanogenic glycosides (phaseolunatin, dhurrin, linamarin, lutaustralin), goitrogens (pro-goitrins, glucosinolates), oestrogens (flavones, genistein), saponins (soya sapogenin), gossypol from Gossypium species, such as cotton, tannins (BOAA, DAP, mimosine, N-methyl-1-alanine) [11]. Therefore, it is necessary to adequately process wild species before consuming them. However, during periods of famine or food scarcity, wild species are helpful reserves. Locals have devised traditional methods to detoxify such crops before consumption since they are aware of the possible hazards associated with their use [10].

ANFs in Mustard:

Mustard belongs to the mustard family Brassicaceae of the order Brassicales (previously called as Capparales) which includes over 330 genera and over 3700 species, distributed worldwide [12]. Black mustard, or *Brassica nigra* (L.) W.D.J. Koch (syn.: *S. nigra, B. sinapioides*), is frequently grown for its blackish dark-red seeds, which are stronger and slightly bitter than those of white (*S. alba*) or brown (*B. juncea*) mustard. The main glucosinolate found in black mustard seeds is sinigrin, which can hydrolyze to produce allyl-isothiocyanate (AITC), which has a strong, disagreeable smell [13]. Myrosinase-induced hydrolysis of glucosinolates at neutral pH mostly produces isothiocyanates, which are comparatively stable in aqueous solutions. In contrast, isothiocyanates from glucobrassicin and neoglucobrassicin, which are indolylglucosinolates, as well as sinalbin, may break down to free thiocyanate ions and other metabolites, particularly at higher pH [14]. The glucosinolate sinalbin found in S. alba mustard seeds primarily breaks down into 4-hydroxybenzyl alcohol and thiocyanate ions under physiological conditions (pH 5–7). Other degradation products, such as 4-hydroxybenzyl cyanide or 4-hydroxybenzylnitrile (2-(4-hydroxyphenyl) acetonitrile), were found in acidic environments [15]. The sodium/iodide (NIS) symporter on the basolateral membrane of the thyroid follicular cell is known to be competitively inhibited by the thiocyanate ion generated by the breakdown of glucosinolates. As a result, the thyroid gland's ability to take in iodide is compromised, which may result in less thyroid hormone production [16].

Particularly in Eastern and North-Western India, mustard seeds are recognized as a significant source of edible oil because of their strong, nutty flavour and high smoke point (250 °C) [17]. Wendlinger et al. identified as many as 19 fatty acids in mustard oils, of which, eicosanoic acid (20:1n-9), and erucic acid (22:1n-9) are the predominant compounds. One common ingredient in mustard or rape is erucic acid. Due to its association with myocardial lipidosis and cardiac diseases in experimental rats, foods high in erucic acid are deemed unfit for human ingestion. Consequently, its presence in oils and fats has been limited in a number of countries [18]. However, the dietary allowance of erucic acid may be reduced by cautiously selecting mustard cultivars.

ANF in Khesari (*Lathyrus sativus* L.):

Millions of people in Asia and Africa eat *Lathyrus sativus* L., also referred to as grass pea or Khesari, on a regular basis. The plant is a legume crop that can withstand drought and moderate salinity. For subsistence farmers, the crop is therefore seen as an insurance crop and survival food. Grass peas may be the sole food available during famines brought on by drought, however it is regrettable because over ingestion of *Lathyrus sativus* causes devastating, irreversible paralysis of both lower limbs, primarily in men. This is caused by the presence of either β-N-oxalyl amino-L-alanine (BOAA) or β-N-oxalyl-L-α,β-diamino propionic acid (ODAP), a non-protein amino acid. β-N-Oxalyl-L-diamino propionic acid (ODAP) is a secondary metabolite found in lathyrus, and it is responsible for the neurodegenerative condition known as 'Neurolathyrism'. Since its discovery in 1964, tremendous attempts have been undertaken to eradicate this neuro-active amino acid by somaclonal variability, mutation, and breeding. The full and ultimate success of these endeavours is still in progress [19].

There are reports of 0.5–2.5% of β-ODAP in grass peas [20]. The seeds of 21 Lathyrus species (primarily *Lathyrus sativus* L., *Lathyrus cicera* L., and *Lathyrus clymenum* L.) and several other genera of leguminous plants, including 17 Acacia species and 13 Crotalaria species, contain toxic β-ODAP [21]. Some non-legume species, such as the roots of Panax ginseng, *P. notoginseng*, and *P. quinquefolius*, also contain it [22,23].

ANFs in millets:

The two main anti-nutritional components of sorghum are dhurrin, a cyanogenic glucoside found mostly in the aerial shoot and sprouted seeds, and tannin, a polyphenolic substance found in the grain. Tannins are very low in unpigmented grains and abundant in sorghum with brown pericarp and no Testa. Tannins' primary anti-nutritional effects include decreased voluntary feed intake as a result of decreased palatability, decreased nutrient digestion and utilization, negative effects on metabolism, and toxicity. Hydrogen cyanide (HCN) is rapidly produced by the enzyme action on dhurrin. By deactivating the cytochrome oxidase system, an excess of cyanide ions can swiftly cause anoxia of the central nervous system, which can lead to death in a matter of seconds. However, turning fodder into hay or silage eliminates the toxin [24].

The most extensively cultivated millet species globally, pearl millet (*Pennisetum glaucum* L. R. Br.) is a significant "orphan" cereal. Phytate is the most significant antinutrient compound found in pearl millet [25]. Phytic acid is Myoinositol 1,2,3,4,5,6-hexakis dihydrogen phosphate. It makes up 1–5% of the total weight and is the main form of phosphorus storage. It is a secondary metabolic substance that accumulates during ripening and is thought to function as a nutrient reserve for the seed. Humans can neither hydrolyze nor absorb phytate, as a result, it decreases bioavailability of minerals [26].

AMF in Soybean:

Raw soybeans include Kunitz factor and Bowman-Birk factor, which are trypsin inhibitors that block the digestive tracts protease enzymes [27]. They reduce the activity of the pancreatic protease enzyme trypsin and, to a lesser degree, chymotrypsin, which makes it difficult for monogastric animals and some immature ruminant animals to digest proteins [28,29].

AMF in Broad bean:

The faba bean (*Vicia faba* L.), sometimes referred to as the horse bean or wide bean, is a member of the Fabaceae family. Faba beans can be used as a substitute for dairy and meat products since they are high in fiber, proteins, carbs, vitamins, and minerals. The faba bean's antinutritional qualities make it an underappreciated crop despite its benefits. The main anti-nutrients in faba beans include lectins, vicine, convicine, phytic acid, tannins, saponins, protease inhibitors, and α-galactosides. After taking too many antinutrients, common symptoms include nausea, anaemia, bloating, rashes, headaches, nutritional deficiencies, and many more. Among the techniques used to lessen the antinutritional factor in faba beans include soaking, dehulling, fermentation, germination, cooking, autoclaving, roasting, and extrusion [30].

Remedy:

Heating at ultrahigh temperatures (>100 °C), viz., Autoclaving, pressure cooking, steaming, mild boiling (75 °C-95 °C) or blanching, extrusion, roasting, soaking etc were effective in reduction of anti-nutritional factors, however, pressure cooking was found to be the best for removal of ANFs. Oxalic acid was significantly reduced by both blanching and cooking, whereas phytic acid and polyphenol levels were only significantly reduced by blanching. Moist heat is more destructive to anti-nutrients than dry heat. The most conventional, affordable, and suitable way to lessen anti-nutrients in various pulses is to soak them before cooking. However, a great deal of research is still required to find ways to remove heat-stable anti-nutrients from different foods without compromising their nutritious content [31].

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FUTURE IS BRIGHT WITH THE DRAGON FRUIT CULTIVATION

Introduction

Dragon fruit, also called *pitaya*, is an attractive tropical fruit that belongs to the cactus family. It has a bright pink or yellow outer skin with green scales, and its sweet, soft flesh is filled with tiny black seeds. In recent years, dragon fruit has become very popular because it is not only tasty but also rich in nutrients like vitamin C, fiber, and antioxidants.

Farmers are showing more interest in cultivating dragon fruit because it can grow well in less water, gives good income, and has high demand in the market. Compared to many traditional fruits, dragon fruit requires less care once the plants are established and can give fruits for several years. With proper farming practices, it can be a very profitable crop for both small and large farmers.

Origin

Dragon fruit has its **origin in Central and South America**, mainly in countries like **Mexico, Costa Rica, and Nicaragua,** where it grows naturally in tropical regions. It belongs to the cactus family and was traditionally eaten by local people for its refreshing taste and health benefits. Later, the fruit was introduced to **Asian countries such as Vietnam, Thailand, and the Philippines,** where it became very popular and is now widely cultivated.

In recent years**, India** has also started growing dragon fruit, especially in states like **Maharashtra, Gujarat, Karnataka, and Kerala,** because it can survive in dry areas, needs less water, and gives good returns to farmers. Today, dragon fruit has become a **global fruit crop**, known for its unique look, high nutritional value, and strong market demand.

Suitable Climate and Soil

Dragon fruit is a hardy plant that grows well in **warm and dry climates**. It prefers temperatures between **20°C to 30°C** and can tolerate heat, but it does not grow well in very cold or frosty areas. Too much rain or waterlogging is harmful, so it should be grown in places where the soil drains easily.

The best soil for dragon fruit is **sandy loam or well-drained soil** with a pH between **6 and 7.** Rocky or clay soils are not good unless they are improved with organic matter. Adding **compost or farmyard manure** makes the soil healthier and helps the plant give better yield.

With the right climate and soil conditions, dragon fruit plants can grow strongly and produce good-quality fruits for many years. Good sunlight throughout the year also plays an important role in improving growth and fruit quality. That is why selecting the right location and soil is the first step for successful dragon fruit farming.

Propagation And Planting

Dragon fruit is usually propagated through **stem cuttings**, because this method is faster and gives better results than growing from seeds. A healthy branch of the plant is cut and dried for a day or two before planting, so that it does not rot in the soil. Though seeds can also be used, they take longer to grow and bear fruits.

The plants are normally planted in **pits of about 60 cm × 60 cm × 60 cm** filled with soil and organic manure. Farmers usually plant them in rows, keeping about **2–3 meters distance between plants** so that there is enough space for growth.

Since dragon fruit is a climbing cactus, it needs **support structures** like concrete or wooden poles, along with a circular ring or frame at the top, to help the branches spread and carry the weight of fruits.

Proper spacing, good quality cuttings, and strong supports are very important for getting healthy plants and good yield.

Irrigation and Fertilizer

Dragon fruit is a cactus plant, so it does not need too much water. Still, **regular and light irrigation** is important for good growth and fruiting. The best method is **Drip irrigation**, as it saves water and keeps the soil moist without flooding. During summer, watering once or twice a week is enough, while in the rainy season farmers should make sure there is **no waterlogging**, because excess water can damage the roots.

For fertilization, dragon fruit grows best when both **organic manure** and **chemical fertilizers** are used. Adding **farmyard manure, compost, or vermicompost** to the soil improves its quality and helps the plant stay healthy for a long time.

Proper irrigation and fertilization together ensure that dragon fruit plants remain healthy, give high yields, and produce sweet, good-quality fruits.

Flowering And Pollination

Dragon fruit plants usually start flowering **one to two years after planting**. The flowers are very large, white, and beautiful, and they bloom only at **night.** Each flower lasts for just one night, so pollination must happen quickly.

Some dragon fruit varieties can produce fruits on their own. But in many cases, **cross-pollination** is needed, where pollen from one plant is transferred to the flower of another plant. This can be done naturally by **bees, bats, and moths**, or manually by farmers through **hand pollination** using a small brush.

Proper pollination is very important because it helps in setting more fruits, improving their size, and ensuring good yield. Farmers who assist in pollination usually get **better quality and higher quantity of fruits.**

Harvesting And Yield

Dragon fruit plants start giving fruits **2 about 1.5 to years after planting**. The fruits are ready to harvest **30 to 35 days after flowering**, when the outer skin turns bright red, pink, or yellow depending on the variety. Fruits should be harvested carefully by hand, using clippers or a knife, so that the skin is not damaged.

The harvesting season usually lasts from **June to November** in India, and each plant can produce fruits **multiple times in a year**. The plants can continue giving fruits for **15–20 years** if maintained properly. Timely harvesting ensures that the fruits are fresh, tasty, and get a good price in the market.

Post Harvesting Management

After harvesting, dragon fruits should be handled carefully because their skin is delicate and can get damaged easily. The fruits are first **cleaned to remove dust and dirt**, then sorted according to size, color, and quality. Grading helps farmers get better prices in the market.

For packing, fruits are usually placed in **cardboard boxes or plastic crates** with soft padding to avoid scratches. They should be stored in a **cool place** to stay fresh for a longer time. At a temperature of about **7°C to 10°C**, dragon fruits can be kept fresh for **up to 3–4 weeks.**

Proper post-harvest management not only reduces wastage but also improves the shelf life and market value of the fruit, making dragon fruit farming more profitable.

Economic Importance and Market Potential

Dragon fruit farming is highly profitable because the fruit sells at a **premium price** in the market. It requires **less water and care**, but produces fruits for many years, giving farmers a steady income. Compared to traditional crops like banana or papaya, dragon fruit can provide **higher returns per acre.**

The demand for dragon fruit is growing in India, both for **fresh consumption and processed products** such as juices, jams, and ice creams. There is also good **export potential,** especially to countries in the Middle East, Europe, and Southeast Asia. With proper **grading, packaging, and marketing,** farmers can maximize their profits.

Dragon fruit cultivation is therefore a **high-value and sustainable crop**, suitable for small and large farmers alike. **Its quick growth, high yield, and rising popularity make it a smart choice for modern farming. With awareness and training, more farmers can benefit from this exotic fruit.** overall, dragon fruit farming offers a stable income and a chance to meet the growing demand for healthy and nutritious fruits.

Health benefits of Dragon Fruit

Dragon fruit is not only delicious but also highly nutritious and beneficial for health. It is rich in **vitamin C, B vitamins, and essential minerals** like calcium, iron, and magnesium, which help in overall growth and immunity. The fruit contains **antioxidants** that fight harmful free radicals and protect the body from various diseases.

Its **high fiber content** improves digestion, prevents constipation, and promotes a healthy gut. Dragon fruit also supports **heart health** by helping to reduce cholesterol and maintain healthy blood pressure. Additionally, it is **low in sugar and calories**, making it suitable for diabetes and weight control. Regular consumption of dragon fruit can boost immunity, improve digestion, and contribute to a healthy lifestyle.

Dragon fruit is also known for its **hydrating properties** because it has high water content, which helps keep the body refreshed and energized. Its **natural antioxidants and anti-inflammatory compounds** can help in slowing down aging and protecting the skin.

Future Prospects of Dragon Fruit

The future of dragon fruit farming looks very **promising**. With growing awareness about healthy eating, the **demand for dragon fruit is increasing** in both domestic and international markets. More farmers are shifting from traditional crops to dragon fruit because it provides **higher income, multiple harvests, and long-term benefits.**

Advances in farming techniques, better varieties, and proper **irrigation and fertilization methods** can further improve yield and fruit quality. Government support and training programs are helping farmers adopt modern cultivation practices, making dragon fruit farming more **profitable and sustainable**.

Overall, dragon fruit has the potential to become a **major fruit crop** in India, offering farmers a **stable income and better livelihood** while meeting the growing market demand for nutritious fruits.

Challenges in Dragon Fruit Farming

Despite its high profitability, dragon fruit farming comes with some challenges. The **initial investment** is higher than many traditional crops because of the cost of **poles, trellises, and quality plant cuttings**. Farmers also need proper knowledge about **plant care, irrigation, and fertilization,** or else the yield may be low. Pests and diseases, such as **stem rot and fruit borer**, can affect the plants if not managed properly. Some varieties require **hand pollination**, which is labor-intensive. Additionally, **market fluctuations and lack of awareness** about proper grading, packaging, and marketing can affect profits. Overcoming these challenges with **training, good management, and government support** can make dragon fruit cultivation highly successful and profitable for farmers.

Conclusion

Dragon fruit cultivation is a **profitable and sustainable farming option** for modern farmers. It requires less water, can grow in different soils, and produces fruits for many years. With proper care, irrigation, fertilization, and pest management, farmers can get **high-quality fruits and good income.** The growing demand for dragon fruit in **local and international markets** makes it a promising crop for the future. By adopting improved farming practices and using quality plant materials, more farmers can benefit from this **exotic and healthy fruit**, improving both their livelihood and the availability of nutritious food for consumers.

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EFFECT OF CLIMATE CHANGE ON BUNDELKHAND REGION

Why Bundelkhand Matters? Bundelkhand shows how climate affects poor farming areas. The Kharif season relies heavily on timely rain. Farmers plant crops like pigeon pea, green gram, black gram, sesame, groundnut, and rice during the monsoon. This region often faces droughts. Now, it sees both drought and floods. This pattern hurts crop choices, yields, and earnings. The social and economic effects go beyond farm losses. They impact food security, rural jobs, debt, and migration. Recent monsoons in 2025 highlight this risk. After years with little rain, heavy downpours ruined crops. This happened in many districts.

Comparison of Bundelkhand Rainfall: 2025 vs 2024

Category	2024 Situation	2025 Situation	Implications / Key Insight
Overall Rainfall Level	Mostly normal monsoon, especially in UP districts	Many districts received excess or large excess rainfall	2025 was significantly wetter and more extreme than 2024
Rainfall Pattern	Relatively stable, fewer extreme events	Extreme rainfall spells, cloudbursts, waterlogging	Indicates increasing rainfall volatility and unpredictability
Agricultural Impact	Adequate for Kharif crops; limited damage	Heavy rains damaged Kharif crops, affecting yields	Excess rainfall is harmful, especially in drought-prone regions
Water Storage & Hydrology	Moderate reservoir levels	Dams filled quickly; flash floods reported	Water systems under stress — excess water unmanaged leads to flooding
Flood / Waterlogging Risk	Low to moderate risk	High risk due to sudden heavy rainfall	Greater need for drainage and flood-prevention infrastructure
Bundelkhand's Long-Term Trend	Consistent with declining rainfall trend in research	A wet year conflicting with long-term decline	Single wet year does not change long-term drought vulnerability
Overall Climate Signal	Near-normal monsoon year	Extremely variable and excessive monsoon	Suggests intensifying climate variability in Bundelkhand

Effect of climate change on major kharif crops in Bundelkhand region:

Monsoon timing and strength have become highly unpredictable, making rainfall difficult to forecast. Heavy showers are often followed by long dry spells, shrinking the short window available for planting Kharif crops. During the 2025 monsoon, rainfall suddenly surged by nearly 200%, flooding fields, delaying sowing, and destroying young seedlings. Rising temperatures and increasing heat stress are also shortening crop-growing periods and accelerating soil moisture loss, increasing irrigation needs while reducing yields of heat-sensitive Kharif crops. Research suggests that continued warming will further reduce the productivity of key staple crops. Shifts in rainfall amount and timing are also disturbing groundwater recharge, worsening water shortages during critical growth stages. Studies highlight that these climatic pressures are likely to strain water availability for Bundelkhand’s largely rain-fed agriculture. These physical changes create additional challenges for small farmers, who face delayed planting, higher costs of resowing, increased pest attacks, and wide fluctuations in yields.

Crop losses and lower yields are now more common. Floods kill young plants, waterlogged soils damage standing crops, and drought spells cause flower drop and hinder grain formation. Pulses and oilseeds have been especially affected by recent heavy rains, while rice planting in low-lying areas has been repeatedly disrupted. Excess moisture during ripening reduces grain quality and raises the risk of mold and toxins in oilseeds and pulses, reducing market value. Heat stress during grain formation results in smaller grains and lower protein content. Over time, these changes have reduced cropping intensity and diversification. Uncertain monsoon patterns push farmers to avoid risky Kharif crops, switch to shorter-duration varieties, or even seek non-farm work. This long-term uncertainty is eroding traditional mixed-farming systems that once helped households manage climate risks effectively.

Socio-economic consequences:

Farm incomes in Bundelkhand are highly unstable, and climate shocks are making this volatility more severe. Crop failures directly reduce household earnings, while declining wages for agricultural labour further weaken family finances. Rising food prices reduce purchasing power, and shortages of fodder limit income from livestock through reduced milk or meat production. The heavy rains of 2025 severely disrupted Kharif planting across the region, causing immediate income losses. Many households were forced to use their savings, sell assets, or take high-interest loans to cope with the sudden financial strain. As harvests fail or yields decline, farmers often resort to borrowing to cover input costs and basic household needs. Repeated climate shocks worsen indebtedness, especially among small and marginal farmers who have limited access to formal credit. Surveys from Bundelkhand highlight this challenge, noting that restricted access to bank loans and inadequate crop insurance push many farmers toward informal lenders who charge very high interest rates.

Food security and nutrition are also affected when Kharif crops fail. Lower production reduces both market supply and household consumption. Declines in pulse and oilseed output lead to shortages of affordable protein and healthy fats, reducing dietary diversity. Poor families suffer most, as higher prices for vegetables and pulses force them to shift toward cheaper, calorie-dense but less nutritious foods. Studies across India show that climate-induced yield losses can trigger local food shortages and contribute to nutritional stress, especially among vulnerable groups. Labour markets in Bundelkhand also suffer when monsoon disruptions reduce planting or damage crops. The Kharif season typically generates high demand for agricultural labour, but poor rainfall patterns or floods shrink employment opportunities. Landless labourers and poor households, who depend heavily on seasonal farm work, are left with fewer job options and must accept lower wages or migrate in search of work. Increased competition for limited jobs pushes rural wages downward, reinforcing poverty cycles for the poorest families.

Frequent climate shocks accelerate both seasonal and long-term migration in Bundelkhand. Younger family members often move to nearby cities for temporary construction or informal jobs, which may provide short-term relief but reduce the availability of workers in home villages and disrupt household care responsibilities. Migration can fracture family units, weaken agricultural productivity, and increase uncertainty in farm operations. Studies from the region show a rising trend of migration closely linked to climate stress and unstable farm incomes. These impacts are also gendered, as women frequently bear a disproportionate share of the burden. When men migrate, women take on additional responsibilities related to farm management, livestock care, household work, and water collection. This increased workload, combined with persistent food insecurity, negatively affects their health and limits their participation in decision-making. Women also face restricted access to credit, advisory services, and land rights, all of which reduce their ability to adopt new farming practices or climate-resilient strategies. Although detailed gender-specific data from Bundelkhand is limited, national studies consistently show the same pattern: climate stress deepens existing gender inequalities and increases the challenges faced by women in agriculture.

Community Ties and Local Rule Climate events strain community bonds and local groups:

Repeated crop failures weaken trust in shared buying. They also spark fights over water. Community systems like shared work and seed swaps get stressed. Yet, local groups such as savings clubs, farmer teams, and water groups boost local strength. These groups actively use water saving methods. They also support tree farming and new jobs. Aid groups show that planned projects, like tree farming and water projects, raise earnings. They also cut down on people leaving their homes.

District-wise map of Bundelkhand region

Heavy rainfall accompanied by hailstorm destroy Paddy Crop in Bundelkhand

Recent Events and Research Show Proof Current news and studies offer clear examples.

The extremely heavy rainfall during the 2025 monsoon caused widespread flooding across Bundelkhand. News reports from July 2025 documented record-breaking rainfall that submerged fields and destroyed standing crops, particularly pulses and oilseeds. Farmers were unable to sow on time, and many who had already planted lost their crops to waterlogging. This sudden shift from the region's typically dry conditions had immediate consequences: planting windows were missed,

People migrating to safer areas after intense rainfall in Bundelkhand

repeated replanting became necessary, and farmers urgently appealed for financial support. Surveys indicate that most farmers are aware of changing weather patterns. A study published in Springer showed that farmers recognize the shifts in rainfall and rising temperatures, and many have already adjusted by choosing different crops, improving irrigation practices, and seeking additional income sources. However, their capacity to adapt remains uneven due to limited financial resources, inadequate information, and weak group support. Government climate-risk assessments also highlight variations across Bundelkhand, showing that some districts face higher risks because of weaker infrastructure, such as poor roads and limited access to adaptation resources. These differences underline the need for localized planning and targeted interventions.

Farmers and community groups employ a range of strategies to cope with these challenges. They replant crops after losses, adjust sowing dates, and select less risky or traditional seed varieties. During shortages, households often rely on purchased food or loans. On their farms, they adopt fast-growing crop varieties, diversify crops, integrate tree-based farming, build soil bunds to prevent erosion, use mulching to conserve moisture, and implement rainwater harvesting to improve groundwater recharge. Evidence from aid organisations and researchers shows that these measures strengthen resilience and improve income stability. Farmers also increasingly access weather advisories, use small-scale irrigation systems such as drip and sprinkler technology, buy crop insurance, and borrow more easily from formal sources. These tools help reduce risks, but adoption remains limited due to high costs, lack of awareness, and delays in insurance payouts. Households with better access to credit and timely weather information are consistently more likely to invest in resilience-building practices.

Policy Gaps and Obstacles Despite many efforts, key issues hinder effective resilience:

Bundelkhand's resilience efforts face several major challenges. The region's division between two states complicates the coordination of water management, irrigation planning, and disaster response. Crop insurance systems add to the difficulty, as payouts are often delayed, coverage for quality loss is weak, and many small farmers are left out altogether. Financial and technological limitations further restrict progress, with smallholders struggling to access loans due to lack of collateral, which prevents them from adopting improved tools and practices. In addition, unreliable weather forecasts and limited advisory services affect farmers' decisions on planting and pest management. Market-related risks also undermine income stability, as price fluctuations following crop failures reduce earnings, and inadequate storage facilities force farmers to sell their produce at low prices.

Suggested Actions To lessen climate change's impact on Kharif crops in Bundelkhand:

Strengthening climate resilience in Bundelkhand requires a combination of locally focused agricultural, social, and policy interventions. Promoting fast-growing and climate-resilient Kharif crops, improving pest management, enhancing soil health, and encouraging crop diversification suited to local weather conditions can help stabilise production. Ensuring water security is equally important and can be achieved through investments in small irrigation systems, groundwater recharge structures, rainwater harvesting, and watershed restoration, along with stronger community-managed water initiatives. Risk protection measures must be improved by reforming crop insurance to provide faster and more transparent payouts, expanding coverage to include crop quality losses and replanting needs, and linking insurance with rapid cash assistance. Financial access and market support are also critical, including easier bank loans for farmers, strengthened farmer groups for collective marketing, and better storage facilities to reduce distress selling. Delivering timely and localised weather information, mobile-based advisories, and practical farmer training can guide better planting and management decisions. Social protection measures—such as post-disaster cash assistance and support for non-farm employment—can help vulnerable households manage shocks and diversify their income sources. Women farmers should receive targeted support through improved access to loans, inputs, and extension services, with programmes designed to reflect their essential roles in agriculture and household management. Finally, coordinated planning between the two states of Bundelkhand, guided by district-level climate-risk assessments, is necessary to ensure that interventions are focused where they are most needed and most effective.

There are gaps in district-level rainfall data because publicly available government monsoon reports often do not provide detailed or easily accessible information for every district. Understanding rainfall trends also depends on the definition of "normal," which is based on the long-period average (LPA); however, this baseline can itself shift over time due to climate change. In addition to total rainfall, its distribution across days and months is critically important. Even when the overall rainfall is high, short, intense bursts can lead to surface runoff rather than effective soil moisture recharge, reducing the actual benefits for agriculture and water conservation. Climate change is changing farming in Bundelkhand. Kharif crops now face new risks and chances. Farmers, many with little land, get fewer steady yields. They face income drops and food worries. But it's not all bad. New ideas like tree farming and water saving are helping. Stronger groups and better loans also boost security. The 2025 floods show we must plan for big weather events. Policy must focus on quick help and lasting changes. To help people and stop rural hardship, Bundelkhand needs focused plans. These plans must include women. They should fit local needs. They must join climate facts with farm life and markets.

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INNOVATIVE POST HARVEST TECHNOLOGY FOR FOOD PRESERVATION

Introduction

Post-harvest technology is a branch of agriculture in which we deals with the process of pre harvesting, harvesting, and post harvesting agricultural products. Which help to enhance the food quality and safety, reduce losses, and extend the shelf life. It includes preservation of food, processing, packaging, storage, handling, Transportation, marketing. It is a real world application of the technology of food and science. It is the route in which food comes from the farm and reaches to the plate of the consumer easily. Innovative post-harvest technologies become important tools for dealing with these problems. This technology makes food last longer by making storage, transportation, and processing easier. This field include different method like cleaning, grading, packaging, storage of crops. It also includes many processing method like drying, milling, preservation to reduce waste. Effective post-harvest technology is very important for farmers' economic gains. It also helps to maintain the nutritional quality of the food which is very essential to minimise the losses and rich the market demand.

Importance of post-harvest technology

• Preservation of food plays very important role in reducing wastage and maintain sustainability.
• Maintaining the safety and quality of the food is very essential .By the proper handling, processing and storage the nutritional quality of the food increases.
• By transforming the raw agricultural products into higher value items like jelly, jam, pickles, etc. which increases the farmers income and generate the opportunities of jobs in the rural areas. It increases the economic stability and also helps in the overall growth of the agricultural industry.
• It increases the overall market value which is beneficial for the farmer.

Traditional Method for Preservation

Some traditional method in which the farmer rely the most

- Sun drying: Drying the fruit, vegetables, cereals, pulses, and spices in the presence of sun.
- Salting and pickling: mainly used for fish and meat preservation.
- Smoking: By smoking the flavour of the fish and the meat get increases.

These methods are all budget friendly and easily accessible, but most of the times it faces high losses due to pest attack, moisture and contamination.

Principles of Food preservation

Proper food preservation depends on various factors to avoid spoilage.

- Microbial control: It is the process in which the growth of the microorganism become reduces by the use of refrigerator.
- Ethylene and oxygen control: It reduces the early ripening of the fruit.
- Moisture management: In this process the activity of the water get reduced which extended the shelf life of the product.
- Enzyme inactivation: It helps to inactivate the enzymes by using pressure temperature heat etc. which help to extend the shelf life of food, protect.

Innovative post-harvest technology

1. Controlled atmosphere Storage (CAS): It is a technique in which the life of the fresh produce is extended by reducing the oxygen level and increasing the CO_2 level. Maintaining the O_2 and CO_2 level also slow down the respiration rate of the fruit and vegetables, delay in ripening of fruits. This method plays important role in long term preservation of fruits, vegetables etc.
2. Modified Atmosphere Packaging (MAP): It is quite similar to the controlled atmosphere but in this process sealed films with natural gasses like nitrogen, oxygen and carbon di oxide are used. It also reduces the respiration rate, microbial growth helping to maintain the food quality.
3. Edible Coating and Biodegradable Packaging: In this process the natural plant based products is used to create bags, films and other products of packaging to reduce the usage of plastic. It also decreases the plastic pollution.
4. Smart and Active packaging: It is the process in which oxygen scavenger and ethylene absorber are used to reduce spoilage of any product. It is a smart packaging technique which also benefited farmers by reducing losses.
5. High pressure Processing (HPP): It is a non-thermal food preservation method in which high pressure of water is used to inactivate the microorganism, enzymes without using heat. It also helps to preserve the food in fresh quality, colour, and flavour with nutritional value. It is very popular and widely used in ready to eat foods, seafood, pet food etc.
6. Pulsed Electric Field (PEF): In this process a high voltage electric pulses is used to create pores in cell membrane which disrupts the cell structure and increased permeability. Mostly it kills the pathogenic microorganism in liquid foods like juices, milk. It also helps in food preservation and starch modification etc.
7. Digital Tools: IoT, AI and Block chain: It is a sensory monitoring system which collects data from environment or any physical assets and provides real time parameters like temperature, humidity, air quality, and pressure. The application of this system is to monitoring the healthcare, infrastructure, environmental as well as livestock management.
8. Value addition of the food: The wastes of cereals, grains are used as fodder crop to feed animals. After processing of fruit the waste like seed, skin etc. are used to make powder which contains protein, pectin, fibre etc. As well as the waste of the vegetables is used as fertiliser for plant this provides nutrition to the plant. Agro-Residue composting increases the fertility of the soil and also helps in smart farming.
9. Refrigeration innovation:
    - Cryopreservation is a technique in which liquid nitrogen is used at

very low temperature which helps to preserve for a long time.

- Many refrigeration trucks are used for long distance transport to reduce the spoilage of food.
- Solar system is also used for refrigeration in some rural areas where the supply of the electricity is very less.
- Thermoelectric cooling systems are also used to reduce the spoilage and extend the shelf life of the product.

10. Innovative harvesting and handling:

- Robotic Fruit Pickers: Autonomous machine with AI, camera, and robotic arm to identify, pick and collect the ripen fruits. It also increases the harvesting efficiency and fruit quality and reduces the labour intensity.
- Sensor-based Handling: Now a days sensor based handling plays important role in reducing the damage during transport, increases the higher quality of yield. There are so many key aspects like conveyor belts, irrigation management, yield monitoring and forecasting, predict crop output and improve logistics.

Challenges in Adaption

There are so many advantages of the innovative post-harvest technology but it also faces some challenges

- The initial cost of the machinery and their equipment are very high.
- In the rural area farmer doesn't have any knowledge of the modern technology and method.
- Internet connectivity as well as the infrastructure is very poor in rural area so that it creates difficulty to implement the new technology and machinery.
- Sustainability is a big problem in rural area because it requires high energy to perform the work.

Future Prospects

- Using solar panel, multi-functional biodegradable packaging help to increase the environmental sustainability.
- Development of packaging, implements of the sensor will help in the early detection of the spoilage and wastage of the food in molecular level which make the food available in the market everywhere.
- Increases the using of the new technologies like AI, Drone, Robotics, new machinery in the field of agriculture help to increase the production of the yield.
- Good transportation is also the important factor to increase the availability of the food.
- Many policies are present which help in the improvement of the rural infrastructure to grow the agriculture for future aspects.

Conclusion

Now a day the journey of the food from the producer to consumer is becoming very difficult so the globalization of food trade increases. As a result the safety and the quality of the food are facing challenges. Post-harvest losses increase the environmental degradation, economic losses etc. Innovative harvesting, smarter storage technology, modern processing, advanced drying, effective packaging, value addition, environmental sustainability help to reduces the waste material and post-harvest losses. It also ensures the sustainability and transparency of the product. Post-harvest technology help to reach the nutritious, safe, and high quality product to consumer's plate without any losses.

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Synthetic Microbial communities (SynComs): Designing life for Agriculture

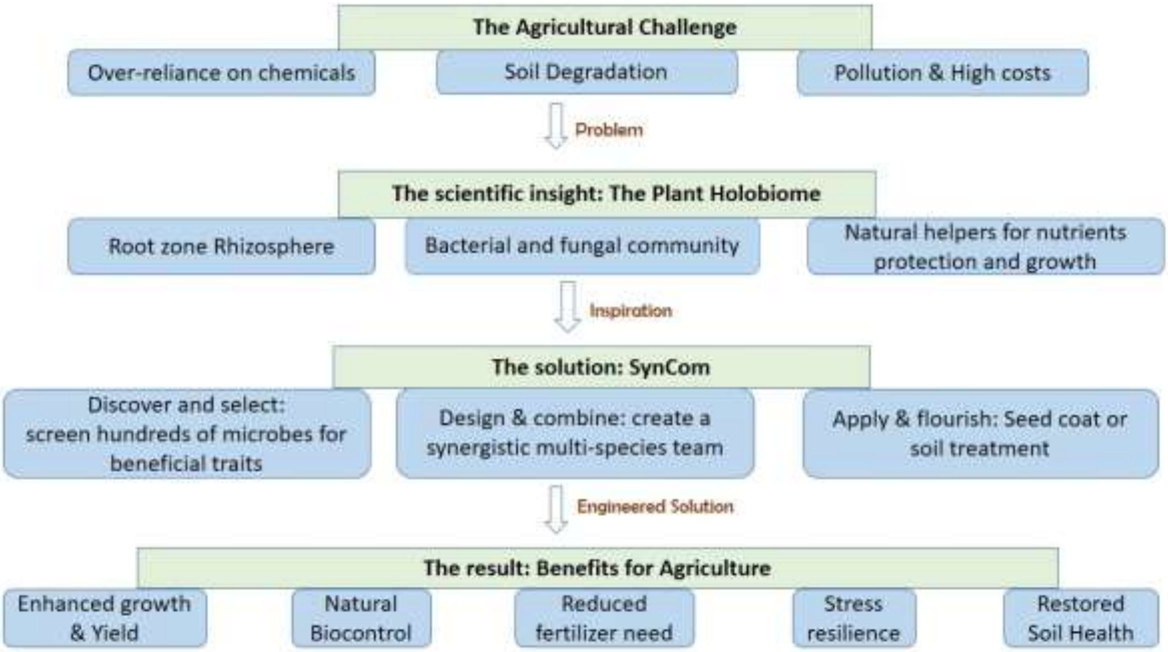
Agriculture always depended on the hidden world of microbes that live in soil and around plant roots. These microbes play a vital role in nutrient cycling, plant growth promotion and protection against pests and diseases. However, natural microbial populations are often unpredictable, influenced by soil type, climate and farming practices. To overcome these challenges, scientists are now building synthetic microbial communities (SynCom) - tailor made groups of microbes designed in laboratories to perform specific agricultural tasks.

What are Synthetic Microbial Communities (SynComs)?

Synthetic Microbial communities are engineered assemblies of different microbes that work together to promote plant growth, yield and health. Unlike naturally occurring populations, SynComs are carefully selected for compatibility and function. SynCom is a simplified consortium derived from the core microbiome of the plant, yet it retains the essential functions of the original community. SynComs represent an ecological and genetic based strategy for developing effective microbial inoculants.

Why are SynComs important for Agriculture?

1. **Food Security**: By 2050, nearly 10 billion people will need food, and SynComs can sustainably enhance crop yields. By restoring the native microbiome, they can also improve nutrient availability, ensuring better food quality and nutrition.
2. **Declining Soil fertility**: Overuse of fertilizers and pesticides has damaged natural soil microbes, leading to poor soil health. SynComs reintroduce beneficial microbes that rebuild fertility and support long term Productivity.
3. **Climate stress**: Crops often face drought, salinity, and heat stress due to climate change. SynComs help the plant to adapt and survive under harsh climatic conditions, making harvest more reliable.
4. **Sustainable farming**: Farmers heavily rely on costly chemical inputs that harm the environment. Overtime this reliance contributes to pollution and biodiversity loss. SynComs reduce this dependency by naturally boosting plant growth and protecting crops, promoting ecofriendly farming.



Benefits of Synthetic Microbial communities

1. **Nutrient mobilization:** SynComs contain microbes that can fix nitrogen, solubilize phosphorus and release potassium for plant uptake. This improves plant growth and yields while reducing the need for excessive fertilizer use.
2. **Stress Resilience:** Crops often suffer from drought, salinity, and heat stress. SynComs help plants adapt by regulating hormones and strengthening roots, ensuring more reliable harvests.
3. **Disease management:** Harmful pathogens threaten plant health and reduce productivity. SynComs protect crops by competing with pathogens and producing natural antimicrobial compounds, lowering need for pesticides.
4. **Yield Enhancement:** By improving nutrient use and protecting from stress, SynComs directly boost crop performance. Stronger root systems and healthier shoots lead to better harvests. For farmers, this means improved income and long term productivity.
5. **Environmental Safety:** Excessive chemical inputs in farming contribute to soil degradation, water pollution, and biodiversity loss. SynComs provide a natural alternative that supports healthy soils and ecosystems. In this way, they align with sustainable agriculture and environmental conservation goals.

How SynCom inoculant different from microbial inoculant?

Traditional microbial inoculants usually contain just one or two strains, each offering a single benefit, but they often fail to survive long in the soil or work consistently across crops. On the other hand, SynComs bring together groups of microbes chosen through ecological studies, so they mimic plants natural core microbiome. This approach allows SynComs to provide multiple benefits at once, stay active in soil for longer, and perform reliably across different crops and conditions. Unlike conventional inoculants that only supplement fertilizers, SynComs have the potential to fully replace chemical inputs, making farming more sustainable.

Challenges

- **Field Survival:** Lab-designed microbes may struggle in diverse field conditions.
- **Complex Soil Ecology:** Natural microbial interactions are difficult to replicate.
- **Regulatory approvals:** Biosafety checks are required before large-scale use.
- **Farmer Awareness:** Adoption requires trust and training at the farm level.

Future outlook

The dream of designing life for crops is becoming real. With advances in genomics, bioinformatics, and synthetic biology, SynComs could soon be as fertilizers in agriculture. Instead of farming with chemicals alone, tomorrow's farmers may farm with precision-made microbial allies.

Conclusion

Synthetic microbial communities are a step toward designing life for agriculture. By carefully assembling beneficial microbes, we can create resilient crops, healthier soils, and a sustainable farming future. These invisible allies beneath our feet may become the most powerful tools feeding the world.

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AI IN AGRICULTURE: USES AND OPPORTUNITIES

Agriculture today is undergoing a profound transformation beyond traditional practices of sowing seeds and waiting for rain. The sector faces unprecedented challenges such as climate change impacts, increasing scarcity of water and soil nutrients, labour shortages and the need to feed a rapidly growing global population. In this evolving landscape, artificial intelligence (AI) emerges as a game-changing tool that brings precision, efficiency and innovative solutions to farming. AI enables machines and systems to learn from data, make timely predictions and automate decisions that enhance crop monitoring, pest and disease detection and resource management at a highly granular level. This technology empowers farmers to apply water, fertilizers and pesticides precisely where and when needed, reducing waste and costs. Integrated AI systems also support yield forecasting, optimal planting and harvesting schedules and even drive autonomous farm machinery, addressing labour shortages while boosting productivity. By leveraging AI-driven insights and automation, agriculture is becoming smarter, more sustainable and capable of responding dynamically to environmental and market variability, securing food production for the future.

What AI brings to the field

AI, at its core, means machines or systems that learn from data, make decisions or predictions and often act on those predictions. In agriculture, that means things like detecting a pest outbreak before it becomes a major problem, applying just the right amount of water or fertilizer in a micro -zone of a field, or using smart machines to reduce labor costs.

Key Use Cases

Here are some of the exciting uses of AI in agriculture:

- **Crop Monitoring & Disease/Pest Detection:** AI systems using computer vision, drones, ground sensors and machine learning can monitor crops, spot early signs of disease or pest infestation and give alerts so farmers can act fast. Studies show that image -based AI models can detect plant diseases with high accuracy. For example, mobile apps exist where a farmer uploads a photo of a leaf and within seconds gets a diagnosis and guidance

- **Precision Resource Management (Water, Fertilizer, Inputs):** One of the big wastes in agriculture is applying water or nutrients across the board, even where the crop doesn't need them. AI -driven systems use soil moisture sensors, weather forecasts, crop growth models and machine learning to optimize irrigation and fertilizer application. This saves resources and reduces cost. For instance, smart irrigation systems have helped farms reduce water usage and increase input efficiency.
- **Yield Prediction & Decision Support:** Using historical data, remote sensing imagery, weather data and AI models, farmers and agronomists can predict yields, plan crop rotations and decide when to plant or harvest. These decision -support systems help reduce risk and improve planning
- **Automation, Machinery & Robotics:** AI is driving smarter machines like robots, drones and autonomous tractors which can do tasks such as weeding, harvesting, spraying, or monitoring with minimal human input. This is especially important given labor shortages.
- **Supply Chain, Market & Value -Chain Optimization:** AI isn't just in the field - it's also in the warehouse and market. Predicting demand, optimizing logistics, reducing waste, matching supply with demand - AI can help farmers get better value for their produce.

Why this matters

- **Greater productivity:** earlier interventions, optimized inputs and better planning lead to higher yields.
- **Resource conservation:** better use of water, nutrients, less waste.
- **Risk reduction:** smarter decisions help farmers manage climate variability and pest/disease threats.
- **Economic benefits**: lower costs, better profits, more efficient operations.
- **Sustainability**: less chemical over -use, better environmental outcomes.

Challenges to consider

Of course, there are hurdles:

- **Data and infrastructure:** Good AI needs good data, good sensors, connectivity - many farms (especially small ones) may lack these.
- **Cost and accessibility:** Technologies may be expensive or difficult to deploy in small - holder contexts.
- **Skill -gap and adoption**: Farmers need training, trust and support to use AI effectively.
- **Generalization and robustness:** AI models trained in one region/crop may not work straight in another without adaptation.
- **Ethical/Policy issues:** Data privacy, ownership, the digital divide between large and small farmers.

Implications for Future Farming

Looking ahead, AI will likely become part of "smart farms" where sensors, drones, AI and human decision -making work together. For example, in horticulture (which you're involved in), AI could help optimize micro -irrigation, monitor tree health for perennial crops, or predict fruit yield and quality. AI also has strong potential in countries like India: tailored advisory apps, affordable drone/monitoring services, small - holder -oriented systems. But to fulfill that promise, we need appropriate infrastructure, training, supportive policy and business models that make it viable for all farmers, not just large ones.

Conclusion

In summary, artificial intelligence is rapidly becoming a transformative force in agriculture - offering smarter monitoring, better decision -making and more efficient use of resources. While challenges remain, the potential is vast. As farming systems evolve, AI will play a key role in enabling agriculture that is productive, sustainable, resilient and inclusive. For researchers, practitioners and policymakers alike, integrating AI into agriculture isn't just an opportunity, it's becoming a necessity for meeting future food security and environmental goals.

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GROWING MUSHROOMS SUSTAINABLY IN RURAL INDIA

Introduction

Mushroom cultivation has emerged as a significant agricultural activity in rural India, providing nutritional, economic, and environmental benefits at a time when small and marginal farmers are facing increasing challenges. Mushrooms are rich in vitamins B and D, antioxidants, fibre, and protein, and unlike many conventional crops, they require very little land and water. They can be grown on agricultural waste and food waste, making them a sustainable option in regions affected by climate change, desertification, and shrinking farmland. In areas such as Solan in Himachal Pradesh, known as the Mushroom City of India, mushrooms have become a dependable source of income for young people, women, landless labourers, and small farmers. Despite favourable conditions, India's mushroom production remains low, per capita consumption is under 100 grams per year, and public sector involvement is limited. This article brings together insights from two reports to highlight low-cost technologies, appropriate infrastructure, government initiatives, and scientific advancements that can support sustainable mushroom cultivation across rural India.

1. Evolution of mushroom cultivation and India's production potential

Mushroom cultivation has a long history. Shiitake and winter mushrooms were grown on wooden logs in China more than a thousand years ago, while button mushrooms began cultivation in France about four hundred years ago. In 1960, white button mushrooms accounted for nearly 80 percent of global production, with shiitake mushrooms contributing 15 percent and other mushrooms making up only 5 percent. Over the decades, production of non-button mushrooms has increased sharply. Today, six major mushrooms like shiitake, oyster, wood ear, button, winter mushroom, and paddy straw account for 90 percent of world production. China cultivates nearly 60 species and remains the largest producer.

In India, mushroom cultivation includes button, oyster, paddy straw, and milky mushrooms, while some valuable varieties such as morels continue to be collected from forests. Although India has an ideal agro climate, abundant crop waste, and low-cost labour, national production is only about 0.13 million tons. Per capita consumption remains under 100 grams per year. Spawn demand is estimated at 8000 to 10000 tons annually, with only 10 percent supplied by the public sector. Significant innovations exist, such as the pink oyster mushroom Arka OM 1 developed by ICAR IIHR. This variety was collected from the Western Ghats and released in 2011. It has a very short cropping cycle of 20 to 23 days and improved shelf life, although documentation of further developments remains limited.

Figure 1: Mushroom growing in Tier System

2. Low-cost substrates, infrastructure, and post harvest innovations

Substrates provide the nutrients, structure, and moisture required for mycelial growth. Several low cost and locally available substrates are widely used in rural India. Straw from wheat, rice, or barley is inexpensive and rich in cellulose. Sawdust or wood chips from hardwood trees can be mixed with bran or gypsum for added nutrition. Rice bran enhances the nutrient content of other substrates. Coffee grounds, which are already pasteurised during the brewing process, offer an easy starting point for small scale growers. Cardboard can be used for oyster mushroom cultivation and is simple to prepare by soaking and draining. Animal manure from cattle, horses, or poultry is effective for button mushrooms. Used or spent substrate can be recycled as compost or reused for preparing new beds, reducing costs and supporting sustainable practices.

Low cost infrastructure designs make mushroom cultivation accessible to small and marginal farmers (Figure 1). Simple mushroom houses can be built using bamboo or wooden poles instead of metal frames. Paddy straw or coconut thatch can be used for roofing. Wooden shelves arranged in four or five tiers can hold substrate bags, while wet gunny bags over windows help maintain humidity and darkness during the spawn running stage. The hanging bag system, where bags are tied to bamboo ceilings, is used in several states including Haryana, Uttar Pradesh, and Uttarakhand. A basic mushroom shed using bamboo, thatch, polyethylene sheets, ropes, and paddy straw costs about Rs 5570. Essential tools include bamboo inoculation hooks, hand sprayers, stoves for sterilisation, and trays for substrate handling.

Post harvest processing plays a major role in increasing income. Traditional methods include sun drying mushrooms, grinding dried mushrooms into powder, and preparing mushroom pickles. Sun drying enhances vitamin D2 content. Mushroom powder has a long shelf life and can be used in cooking. Newer processing innovations include high pressure processing, freeze drying, electro fluidic drying, cold plasma treatment, and advanced packaging techniques. Public sector institutions have also developed value-added products such as iron-fortified mushrooms, mushroom-fortified rasam powder, and mushroom chutney pudi.

3. Government support and socio-economic impact

Government schemes provide financial and technical support for mushroom cultivation. The Mission for Integrated Development of Horticulture offers subsidies up to 50 percent for mushroom units, including support for compost. Under the Rashtriya Krishi Vikas Yojana, states such as Kerala promote mushroom cultivation through small scale mushroom units, hi tech milky mushroom units, spawn production units, minimal processing units, and vermicompost units. The Kerala Agricultural University and Krishi Vigyan Kendras provide training in spawn production, substrate sterilisation, casing soil preparation, environmental control, and value addition.

Studies from Himachal Pradesh show that mushroom cultivation has a strong socio-economic impact. A survey of 60 mushroom growing families revealed full literacy among farmers and relatively high education levels. With an average landholding of only 0.82 hectares, most of which was orchard land, farmers dedicated a very small portion to mushroom sheds and still earned substantial income. On average, mushrooms contributed 48.42 percent of total family income, with large farmers earning up to 72.18 percent of their income from mushrooms. Many farmers earned more than Rs 52000 per month from fewer than 1200 bags. The study also showed that literacy played a significant role in technology adoption, while landholding and family size had a minimal influence.

4. Clean cultivation, pest control, and smart farming opportunities

Pest and disease management is essential to maintain mushroom quality and prevent crop loss. Cleanliness, moisture control, proper ventilation, and regular disinfection of tools are necessary. Sciarid flies are common pests. Biological control measures include beneficial nematodes and the bacterium Bacillus thuringiensis. Yellow sticky traps help capture flying insects. Regular monitoring and record keeping help farmers detect early signs of infestation and take timely action.

Simple smart farming tools can greatly improve efficiency. Low cost sensors for temperature, humidity, carbon dioxide, and substrate moisture allow farmers to maintain optimal conditions. Automated irrigation and humidity systems, including drip irrigation and closed loop humidity controllers, maintain moisture levels between 85 and 95 percent while preventing mould growth. Training in spawn production, substrate preparation, waste recycling, casing soil management, and marketing allows farmers to improve productivity and profitability.

Conclusion

Insights from both articles clearly show that low-cost technologies, public sector research, innovative substrates, smart farming tools, and targeted government support can strengthen mushroom cultivation across rural India. Scientific advances, such as Arka OM 1, iron-fortified mushrooms, and improved processing techniques, have tremendous potential; however, many of these innovations have yet to reach farmers due to limited documentation and dissemination. By expanding training opportunities, improving public sector spawn supply, promoting affordable infrastructure, and making research accessible to rural communities, mushroom cultivation can become a sustainable, profitable, and nutrition enhancing enterprise for small and marginal farmers in India.

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FUTURE IS BRIGHT WITH THE DRAGON FRUIT CULTIVATION

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Abstract:

Climate change has emerged as a major threat to global agriculture, with rising temperatures, unpredictable rainfall, and frequent extreme weather events severely affecting crop growth and food security. Heat stress, altered crop cycles, unseasonal rains, and disasters such as floods, droughts, and storms are reducing yields, disrupting supply chains, and increasing the risk of hunger, particularly in developing regions. Events like the 1997–98 El Niño and recent FAO projections highlight the magnitude of potential crop losses and the growing vulnerability of farming communities. To address these challenges, adopting sustainable agricultural practices, improving water-use efficiency, and developing stress-tolerant crop varieties are essential. Strengthening these adaptation strategies will help build resilient food systems and ensure a stable food supply in the face of a changing climate.

Introduction:

Climate change is a pressing issue with far-reaching consequences for our planet. One of the most significant impacts of climate change is its effect on crop yields and food security. In this article, we will explore how climate change is impacting agricultural productivity and what it means for our global food force. Climate change manifests in colourful ways, including rising temperatures, changing rush patterns, and increased frequency of extreme rainfall events. These changes directly affect crop growth and development, reducing crop yields and compromising food security. As temperatures rise, crops are exposed to heat stress, which can hamper photosynthesis and lead to reduced yields. also, advanced temperatures can alter the timing of flowering and maturity, dismembering the natural growth cycle of crops. This can affect yield and make it difficult for growers to predict optimal planting times. Extreme rainfall events similar to hurricanes, cyclones, and severe storms are getting more frequent and violent due to climate change. These events can devastate entire crops, leading to significant losses for growers. Similarly, the destruction of structures, such as irrigation systems and storehouse installations, further exacerbates the impact on crop yields and food security. The effect of climate change on crop yields has serious consequences for global food security.

With a growing global population, it's pivotal to ensure a steady force of food. Still, climate change-caused reductions in crop productivity make it grueling to meet the added demand for food. Reduced crop yields due to climate change can lead to rising food prices in the global market, affecting consumers worldwide. also, dislocations in the force chain caused by extreme rainfall events can further complicate food dearth's in affected regions, leading to increased food instability.

Impact of Climate Change on Global Food Security:

According to the United Nations FAO report, climate change will cause India to lose 125 million tonnes, or 18% of its rainfed cereal production in 2015. China's rainfed cereal output potential of 360 million tonnes is predicted to rise by 15% during the same period. It would also result in a global reduction in grain yields, putting 400 million additional people at risk of starvation and three billion people at risk of flooding and losing access to fresh water supplies. Crop production losses due to climate change may also significantly increase the number of undernourished people, impeding efforts in poverty reduction and food security. Climate change has had an impact on food security, either directly or indirectly, by putting a strain on food production. Changes in agroecological circumstances, particularly crop patterns, and productivity, have a direct impact, while interruptions in growth and income distribution, and hence demand for agricultural products, make an indirect influence. Crop yields are more negatively affected in most tropical and subtropical regions than in temperate regions. Because they rely on agriculture for a living, a lack of resources for adaptation measures, and vulnerability to extreme weather events, developing economies are more vulnerable to climate change than industrialized economies.

Climate change has the potential to improve or worsen growing conditions in many places. Temperature, rainfall, and frost-free days are all changing, resulting in prolonged growing seasons in practically every state. A longer growing season can have a beneficial and negative impact on food production. Some farmers may be able to plant longer-maturing crops or multiple crop cycles, whilst others may require more irrigation during a longer, hotter growing season. Air pollution can also harm crops, plants, and forests. The 1997/1998 El Niño event, the strongest of the century, harmed 110 million people and cost the world economy approximately $100 billion. According to the United Nations FAO report, climate change will cause India to lose 125 million tonnes, or 18% of its rainfed cereal production, by 2015. China's rainfed cereal output potential of 360 million tonnes is predicted to rise by 15% during the same period. It would also result in a global reduction in grain yields, putting 400 million additional people at risk of starvation, as well as three billion people at risk of flooding and losing access to fresh water supplies.

Adapting to the Changing Climate:

Climate change will have an impact on agriculture by affecting crops, soils, insects, weeds, diseases, and livestock. As a result, identifying and evaluating strategies for adapting to the effects of climate change in the future decades has become crucial. Climate and agricultural researchers throughout the world are constantly researching new adaptation measures to mitigate the effects of climate change on food security. Such adaptation techniques include reducing the number of fallow years required to maintain soil nitrogen status in irrigated systems and increasing moisture retention in rainfed systems. Furthermore, changes in planting dates and seed rates with more adequate thermal time and vernalization need increased resistance to heat stress and drought and are beneficial climate change mitigation techniques. Reduced abiotic stresses such as heat, drought, flood, water logging, nutrient-deficient soil, and so on, as well as the impact of climate change, require the development of stress-tolerant, higher-yielding, and early-maturing crop varieties through plant breeding and biotechnological approaches.

❖ To mitigate the impact of climate change on crop yields and food security, adaptation strategies are crucial. These strategies involve implementing sustainable agricultural practices, improving water management, and developing climate-resilient crop varieties.

➢ **Sustainable Agriculture: A Path to Resilience:**

Practicing sustainable agriculture can help minimize the negative effects of climate change on crop productivity. Techniques such as organic farming, agroforestry, and crop rotation can improve soil health, conserve water, and enhance the overall resilience of farming systems.

➢ **Enhancing Water Management:**

Efficient water management is vital for crop growth, especially in regions facing water scarcity. Implementing drip irrigation systems, rainwater harvesting, and water-efficient irrigation techniques can ensure optimum water usage and reduce the vulnerability of crops to droughts and floods.

➢ **Developing Climate-Resilient Crop Varieties:**

Investing in research and development of climate-resilient crop varieties is essential for

adapting to changing climatic conditions. Breeding crops that are tolerant to heat, drought, and pests can help farmers overcome the challenges posed by climate change and ensure a stable food supply.

Conclusion:

Climate change poses a significant threat to crop yields and food security. Rising temperatures, changing precipitation patterns, and extreme weather events all contribute to reduced crop productivity and increased vulnerability. By embracing sustainable agricultural practices, improving water management, and developing climate-resilient crop varieties, we can adapt to the changing climate and safeguard our food supply for future generations.

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WIND AND FIELDS: HOW WIND ENERGY IS POWERING NEW OPPORTUNITIES FOR FARMERS

Abstract

Wind energy is emerging as a vital component of sustainable rural development, particularly in agricultural regions where land and livelihood intersect. This article explores the synergies between wind power generation and farming systems, highlighting how turbines coexists with crops and livestock while providing stable income to landowners. By examining economic, social, and environmental dimensions, the discussion underscores how wind farms contribute to climate resilience, energy diversification, and rural prosperity. Real world examples from global and Indian contexts, such as the wind corridors of Tamil Nadu and Gujarat, illustrate both the opportunities and challenges faced by farmers. Furthermore, the article emphasizes the importance of transparent leasing agreements, community engagement, and environmental safeguards for long term success. Overall, wind energy represents not just a technological advancement but a transformative approach to strengthening agricultural livelihoods while addressing global climate goals.

Keywords : Wind energy, Agriculture and Livelihood

Introduction

Wind turbines - tall, elegant white structures on plains and ridgelines, are altering the energy mix more than anything else in the globe. They are subtly changing rural economies, giving farmers new sources of income, and demonstrating how clean energy and agriculture can coexist in the same space. Since wind turbines take up minimal space and may provide consistent income, new local jobs, and climate benefits while farms continue to produce food, many farming families view wind energy as a partner rather than a threat.

Wind turbines are increasingly present on agricultural land, especially in the United States and other leading wind energy countries, but the total share of farms actually using wind energy remains a small percentage of all farmland globally and nationally. As of 2020, more than 90% of land-based wind turbines in the United States were installed on private farmland, yet the actual land directly impacted by wind turbine use was less than 0.05% of total U.S. farmland. In regions such as the Midwest, 94% of rural wind turbine sites were classified as cropland. Globally, wind power accounted for about 8% of the world's total electricity demand in 2020, with continued growth expected.

Why wind fits agricultural land

Because broad fields and ridgelines offer favorable winds and comparatively few construction restrictions, wind farms are frequently located on agricultural terrain. Crucially, a contemporary onshore turbine has a minimal physical footprint; the tower base and access roads take up only a small portion of a hectare, leaving the remaining area free for grazing or crops.

Actual farm income

Wind turbine lease payments and income in India are generally structured in rupees and provide a consistent, inflation-resistant revenue source for landowners, particularly farmers.

Typical Lease Payment Rates :

Land lease rates for wind farms are often set between ₹10,000 to ₹30,000 per MW (megawatt) per year, depending on the state policy and whether the land is private or government-owned. For example, in Gujarat, land lease rent has been fixed at ₹10,000 per hectare per year for wind farm projects on government land. The Ministry of Environment previously required a lease rent of ₹30,000 per MW per year for wind projects, but this rate has since been relaxed in many cases to encourage more wind energy development.

Direct Farmer Income:

If a farmer hosts multiple turbines (say, 2 MW on their land), they might earn ₹20,000–₹60,000 per year or more, just through land lease rent, with virtually no loss of productive area. Some wind power agreements may also include performance-based bonuses or a share of electricity revenue, but the predominant model in India is a fixed lease (usually per acre/hectare or MW).

Benefits to Farmers:

Lease income is predictable, paid annually (or as per contract terms), and separate from crop or livestock sales, ensuring an alternate flow of funds. This additional revenue can be used for debt repayment, machinery purchases, farm improvements, family commitments, or investing in more sustainable practices. Farmers continue regular cultivation or grazing since wind turbines occupy a tiny physical footprint relative to total farmland area.

Tax and Community Advantages:

Wind projects also contribute to local panchayat or state taxes and can bring infrastructure improvements to rural areas. In regions with higher wind penetration, aggregate lease and tax benefits have reached crores of rupees annually for the rural economy. In summary, wind energy provides Indian farmers with consistent, long-term income in rupees, secures them against agricultural volatility, and supports community infrastructure, all while allowing uninterrupted farming activities.

Farming goes on beneath the turbines

Modern wind farms are made to interact as little as possible with farming activities. Sheep and calves graze the pasture without causing significant disturbance, and typical layouts allow tractors and harvesters to go directly up to the turbine fencing.

Environmental trade-offs: effects on local populations and animals

By replacing fossil fuel generation, wind energy lowers greenhouse gas emissions and provides definite climate advantages that promote long-term agricultural resilience. However, there are local environmental obligations associated with wind projects as well.

Snapshots of case studies (India and beyond)

Wind power has surpassed significant installations and capacity benchmarks worldwide, expanding the industry's reach into agricultural areas from North America to Europe and Asia. Wind energy has grown quickly in India, particularly in Gujarat and Tamil Nadu, generating revenue and jobs while preserving agricultural land.

Community and social factors

When local communities are involved and not just receivers, wind projects have the best chance of success. Conflict can be avoided with explicit assurances on access and maintenance schedules, equitable compensation, and transparent contracts.

Practical concerns for farmers to weigh

When you receive an offer, think about things like: How long is the lease? Access roads are maintained by whom? What takes place during decommissioning? A reasonable lease can change a farm, but a bad contract might force a farm into unfavorable conditions, so it's a good idea to read the fine language or get independent legal counsel before signing.

Optimizing win-win results: concepts for design and policy

Wind plus agriculture can help local communities and the environment through strategic siting, flexible contracts, community benefit initiatives, and environmental protections.

Looking ahead: technology and integration

Advances in turbine technology, forecasting and hybrid systems will expand renewable capacity and offer new opportunities for farmers.

Conclusion

The incorporation of wind energy into agricultural settings shows that advancements in renewable energy don't have to come at the price of rural identity or food production. Wind farms, when properly designed, protect farming operations, diversify revenue streams, and lessen susceptibility to climate change. Additionally, they promote innovation in regional economies, igniting the maintenance, logistics, and renewable services sectors that create jobs locally.

However, fair lease practices, environmental monitoring, and equal policy frameworks are necessary for this synergy to continue. Mutual trust and long-term gains are ensured when farmers and rural communities actively participate in decision-making. The collaboration between wind energy and agriculture provides a paradigm of balance between sustainability and productivity as the globe moves closer to becoming carbon neutral, demonstrating that clean energy and lush fields can actually coexist.

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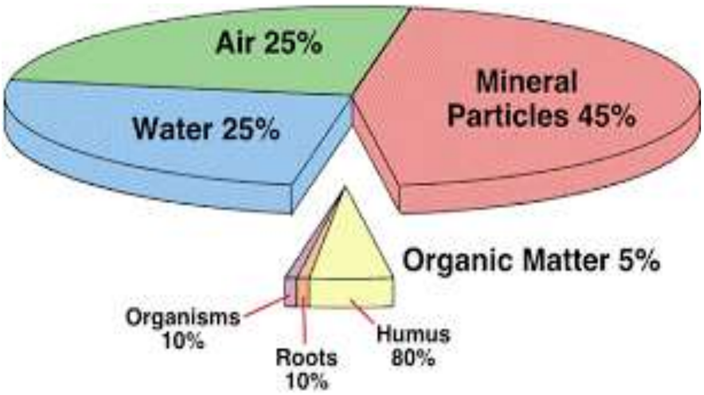
SCIENTIFIC METHOD OF SOIL SAMPLING : DIRT TO DATA FOR BETTER SUSTAINABLE FARMING

What is Soil Composed of?

Soil is a perfect blend of essential components that support plant growth. It consists of 45% minerals that form its structure, 25% water that hydrates plants, and 25% air that provides oxygen for roots and microbes. The remaining 5% of soil composition is organic matter, consisting of both living and non-living components; like soil- dwelling microbes, flora and fauna, decomposed plants and animals, as well as organic residues that enrich the soil with essential nutrients, improving its fertility and structure. This balanced composition ensures fertility, proper drainage, and a healthy environment for crops.



Major Components of Soil

Why is Soil Testing Important?

- Soil plays a vital role in plant growth and directly affects crop productivity. Since soil conditions vary, testing helps assess soil health and nutrient levels.
- A soil test determines the availability of essential nutrients, soil pH, organic matter content, and electrical conductivity. These insights help in recommending fertilizers, ensuring balanced nutrition for crops.
- Soil sampling increases farmers' profit by decreasing unnecessary input costs while ensuring better returns on investment.
- It improves overall soil health by identifying and correcting nutrient imbalances, leading to long-term soil fertility.
- Soil testing helps farmers make smart, data-based decisions, leading to better crop management.
- Soil testing reduces environmental damage by preventing excess nutrient runoff.

Soil Sampling

Soil sampling is crucial for effective soil testing and ensures accurate results. A precise sampling method is essential, as even advanced testing can't make up for poor practices. Proper soil testing reveals nutrient levels and soil health, helping farmers make informed decisions to improve crop yields.

Soil is analyzed to know the nature of soil, to classify and advocate to farmers about the peculiarities of the soils and how much of fertilizers should be applied for better crop production.

The value of the laboratory work depends upon care in sampling. Each soil sample needs to be a fair representative of the specific area or horizon worth sampling.

If the sample is to be a representative of an area, it is necessary to take large number of samples covering the entire are under sampling, pool them and sub-sample it so as to get a sample of desired size. For soil survey work, samples are collected from a profile which is typical of the soil of the surrounding area.

Materials Required for Soil Sampling

1. Spade
2. Khurpi
3. Auger
4. Soil testing tube (for wet soil)
5. Sampling bags and
6. Plastic basin or Bucket

Frequency of Soil Sampling

- Annually for Agricultural crops, high-value or sensitive crops, such as horticultural crops, greenhouses, and precision farming.

Spade

Auger

Spade

Sampling Bags

- Soil sampling can be done 6 months after soil amendments
- Soil sampling can be taken Immediately when visible signs of nutrient deficiency, poor plant growth, or pH imbalance.

Optimal Timing for Soil Sampling

- The recommended period for soil sampling is from November to April.
- It is advisable to conduct sampling 2 to 3 months prior to sowing or planting.
- Soil sampling should take place following the harvest of crops.
- The soil should be in a moist state, yet not excessively wet; ideally, sampling should be conducted during dry conditions, avoiding periods immediately after rainfall or irrigation.

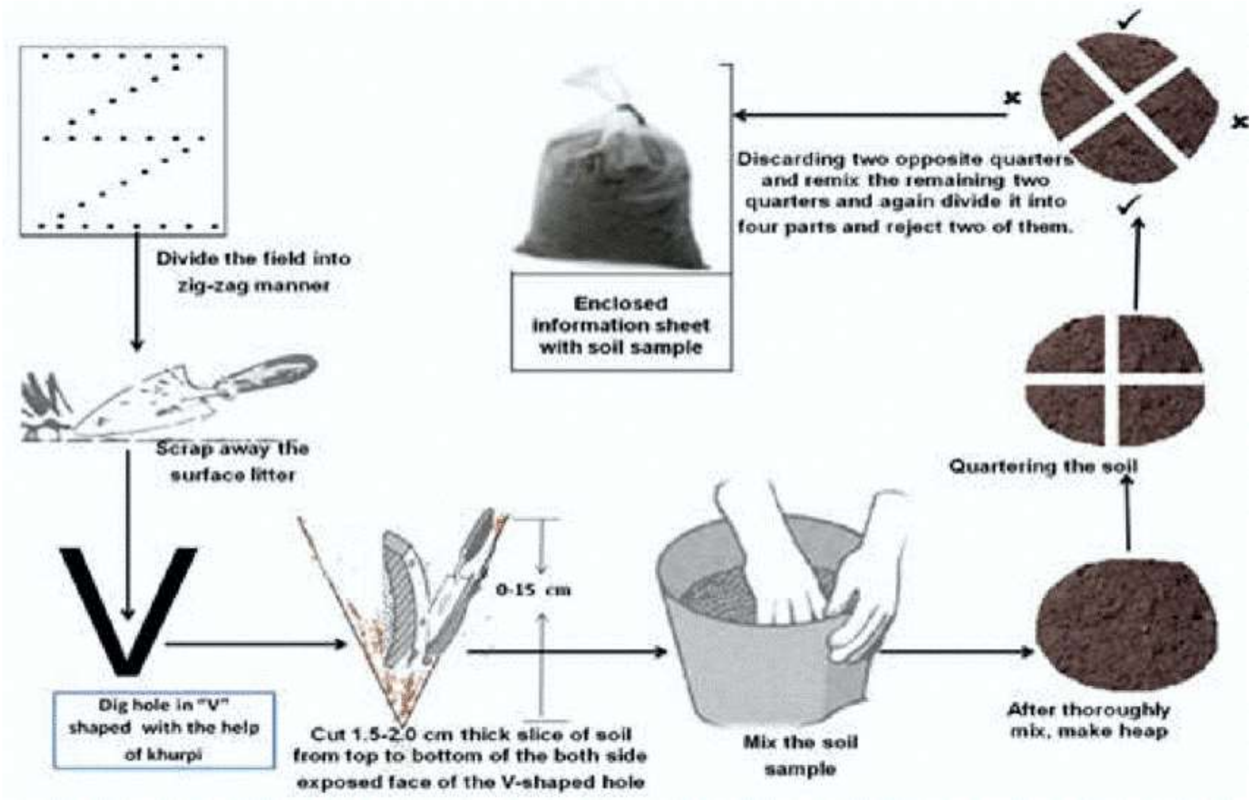
When and where to avoid soil sampling?

Soil sampling should be avoided under the following circumstances:

- Within nine months following the application of rock phosphate.
- Within ninety days after the application of organic manure or phosphorus fertilizers.
- Within thirty days after the application of nitrogen or potassium fertilizers.
- Immediately following periods of heavy rainfall or irrigation or During wet conditions
- In unusual areas, including but not limited to: road margins, undulating terrain, highly sloped lands, labor line sites, areas in proximity to cattle sheds, damp locations, and regions adjacent to shade trees, compost piles, bunds, and channels.
- These precautions will help ensure the accuracy and reliability of soil sampling.

Collection of soil samples from the field

- Normally each field may be treated as a sampling unit. But two or more fields, which are similar in appearance, production and past-management practices, may be grouped together into a single sampling unit.
- Samples should be collected separately from areas, which differ in soil colour or past-management practices such as liming, fertilization, cropping pattern etc.
- During the collection of soil, avoid dead furrows, old manure or lime piles, wet spots, areas near trees, manure pits, compost pits and irrigation channels.
- The sampling should be done in a zig-zag pattern across the field to get homogeneity.
  - A wise soil sample collecting agent is one who collects samples in the presence of the owner or cultivator of the land who is the best judge in deciding which area of his farm should be sampled separately.
  - Scrap away the surface litter and insert the sampling auger to plough depth (15 cm).
- Take at least 15 samples randomly distributed over each area and place them in a clean bucket.
- If a sampling auger is not available, make a 'V' shaped cut to a depth of 15 cm using a spade (in case of field crops) and remove 1.0 to 1.5 cm thick slice of soil from top to bottom of exposed face of the 'V' shaped cut and place them in a clean bucket.
- When conducting soil sampling, it's essential to consider the root depth of the crops in question. For shallow-rooted crops, such as herbs and leafy greens, samples should be collected from the top 0-15 cm of soil, where these plants primarily absorb nutrients and water.
- For deep-rooted crops like potatoes and corn, it's crucial to sample down to at least 30 cm, as these plants extend their roots deeper into the soil to access moisture and nutrients.
- In the case of horticultural crops, sampling depth can vary significantly based on the specific root penetration of each plant species. It is advisable to assess the individual root structures to determine the most effective depths for sampling, ensuring accurate and representative soil analysis for optimal growth.
- Thoroughly mix the samples taken from 15 or more spots of each area.
- Remove foreign bodies such as plant roots, stubbles, pebbles, stones or gravels.
- By Quartering, discard all but 0.5 to 1 kg of soil.
- Quartering is done by dividing the thoroughly mixed soil into four equal parts and discarding two opposite quarters.



- Remix the remaining two quarters and again divide into four equal parts and reject the opposite two.
- Repeat this procedure until to get 0.5 to 1 kg of soil.
- Instead of quartering, compartmentalization method can also be followed.
- For this, spread the soil on a clean hard surface and mark lines from both sides and create number of compartments.
- Take a little quantity of soil from each compartment and put into a clean container.
- Repeat the process of collection until the required quantity of soil is collected.
- Store the soil in a clean bag or container with proper labelling for further analysis.
- Sampling should be done after the harvest of the crop.
- In case the sampling is necessary during crop growth, sample between lines of growing plants.
- Avoid storing samples in fertilizer bags.

Collection of soil samples from a profile

- After the profile has been exposed, clean one face of the pit carefully with a spade and note the succession and depth of each horizon.
- Prick the surface with a knife or edge of the spade to show up the structure, colour and compactness of soil.
- Describe the profile as per the standard terminologies.
- Use Munsell colour chart for noting the colour and find out the texture by feel method.
- Collect the samples from each horizon by holding a large basin at the bottom limit of the horizon while the soil above is loosened by a khurpi.
- The sample is mixed and transferred to a bag after labelling.

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CARBON FARMING: AN INNOVATIVE APPROACH TO MITIGATE CLIMATE CHANGE

INTRODUCTION

Climate change is one of the greatest challenges of the 21st century, with rising greenhouse gas (GHG) emissions threatening ecosystems and food security. Agriculture plays a dual role in this crisis, it contributes significantly to emissions but also has the potential to act as a major carbon sink. Carbon farming is an emerging agricultural strategy that focuses on capturing and storing atmospheric carbon dioxide in soils and vegetation through sustainable land management practices. Unlike conventional farming, which is primarily concerned with short-term yields, carbon farming incorporates ecological sustainability with the goals of improving biodiversity, restoring soil health, and lowering emissions. Higher fertility, better water retention, and increased resilience to climatic extremes are some of the co-benefits of soil carbon sequestration, which the Intergovernmental Panel on climatic Change (IPCC) has identified as a low-cost mitigation method. In addition to its positive effects on the environment, carbon farming offers financial advantages through increased yields, reduced input costs, and access to carbon credit markets. It is essentially a paradigm shift that transforms agriculture from an extractive system to a regenerative, climate-smart strategy that balances farmers' livelihoods with global climate goals.

PRACTICES INVOLVED IN CARBON FARMING

Carbon farming encompasses a suite of agricultural and land management practices designed to capture atmospheric carbon and increase soil organic carbon stocks. These practices vary depending on climate, soil type, and farming systems, but collectively they aim to enhance carbon storage, reduce emissions, and improve ecosystem health.

1. **Conservation tillage and no-till farming:** Reducing soil disturbance is one of the most effective ways to retain carbon in agricultural soils. Conservation tillage or no-till farming minimizes the release of carbon dioxide caused by soil oxidation, preserves natural soil aggregates, and enhances soil structure. This causes organic matter to gradually build up in the topsoil, increasing its fertility and water-holding ability. No-till farming is a viable and sustainable strategy since it also saves farmers money on labour and fuel.

2. **Cover cropping and crop rotation:** Cover crops such as legumes, grasses, and brassicas are used to maintain continuous vegetation cover between main crop cycles. These crops prevent soil erosion, reduce nutrient leaching, and add biomass to the soil, which eventually increases organic carbon content. When combined with crop rotation, cover cropping enhances soil microbial activity, diversifies root systems, and improves resilience against pests and diseases. This makes it a simple yet powerful carbon farming strategy.
3. **Agroforestry systems:** Agroforestry involves the deliberate integration of trees and shrubs into farming landscapes. Trees act as long-term carbon sinks, storing carbon in both biomass and soil through leaf litter and root turnover. Beyond carbon benefits, agroforestry improves microclimates, enhances biodiversity, and offers farmers additional income from timber, fruits, or fodder. In regions vulnerable to climate extremes, agroforestry also provides shade and reduces evapotranspiration, making farms more resilient.
4. **Organic amendments and biochar:** Adding organic inputs such as compost, crop residues, and animal manure enriches soils with stable organic matter while recycling nutrients within the farm. An advanced approach is biochar application, where carbon-rich material from biomass is added to soil. Unlike compost, biochar provides long-term carbon stability, sometimes lasting hundreds of years, while also improving soil aeration, nutrient retention, and microbial activity.
5. **Rotational grazing and integrated farming systems:** Livestock can play a positive role in carbon sequestration when managed properly. Rotational grazing ensures that pastures are not overexploited, allowing grasses to regrow and develop deeper root systems that store more carbon. Integrated farming systems, which combine crops, livestock, fisheries, and forestry, recycle nutrients efficiently and reduce external input requirements. This holistic approach not only sequesters carbon but also enhances overall farm productivity and resilience.

ROLE OF CARBON FARMING IN THE GLOBAL CLIMATE STRATEGY

Carbon farming is emerging as a vital part of the global climate strategy, complementing renewable energy and industrial decarbonization efforts. The Intergovernmental Panel on Climate Change (IPCC) estimates that land-based solutions, including soil carbon sequestration, could provide up to one-third of the mitigation potential needed to meet the Paris Agreement goals. Through practices like conservation tillage, agroforestry, cover cropping, and improved grazing, agricultural systems can transform from greenhouse gas sources to carbon sinks. Initiatives such as the “4 per 1000” launched at COP21 highlight that a 0.4% annual increase in soil carbon could offset significant emissions. Many countries now include soil carbon restoration in their Nationally Determined Contributions (NDCs). Carbon farming supports multiple Sustainable Development Goals (SDGs), including climate action, food security, and poverty reduction. With credible monitoring, equitable carbon credit systems, and strong policies, carbon farming can link grassroots agricultural innovation with global climate commitments, fostering sustainable and resilient ecosystems.

TECHNOLOGICAL INNOVATIONS IN CARBON FARMING

Technological innovations are transforming carbon farming from a traditional set of practices into a data-driven, measurable, and scalable climate solution.

- Remote Sensing and Satellite Monitoring: Advancements in remote sensing and satellite imaging now allow large-scale monitoring of land use, vegetation, and soil moisture, offering key insights into carbon sequestration. When combined with GIS, these tools help farmers and policymakers visualize soil carbon stocks and forecast changes under different management practices.
- Artificial Intelligence and Data Analytics: The integration of **artificial intelligence (AI) and machine learning models** has enabled more accurate predictions of soil organic carbon dynamics. These technologies process large datasets from farms, weather stations, and satellites to recommend site-specific interventions. AI-based models also reduce uncertainty in soil carbon estimation, which is essential for carbon credit verification.
- Soil Sensors and Digital Probes: Innovations such as **soil carbon sensors, probes, and automated respiration monitors** provide real time data on soil health. These tools make it easier to track microbial activity, nutrient availability, and organic carbon changes without the need for expensive laboratory analysis. This reduces costs while improving transparency in carbon measurement and reporting.
- Blockchain and Carbon Markets: To address trust and transparency challenges, **blockchain technology** is increasingly applied in carbon credit trading. By recording transactions in secure, tamper-proof ledgers, blockchain ensures that carbon credits generated by farmers are traceable, verifiable, and free from duplication, which enhances farmer participation and investor confidence.
- Precision Agriculture and Emerging Tools: Technologies such as **drones, automated irrigation systems, and precision nutrient management tools** further enhance the efficiency of carbon farming. Drones equipped with sensors can detect crop stress and optimize fertilizer use, while biochar production units and microbial inoculants add new pathways for soil carbon sequestration.

CHALLENGES IN ADOPTING CARBON FARMING

Despite its potential, carbon farming faces several challenges that limit widespread adoption. High upfront costs for practices like agroforestry, biochar application, and precision farming, coupled with limited access to credit or subsidies, deter smallholders. Although long-term benefits exist, delayed returns discourage participation. Knowledge and capacity gaps further hinder progress, as carbon farming requires specialized skills, training, and extension support. Measurement and verification of soil carbon remain complex and costly due to soil and climate variability, and emerging digital tools are often inaccessible in developing regions. Policy and institutional shortcomings, including the absence of standardized carbon credit frameworks and unclear incentive mechanisms, create uncertainty for farmers and investors alike. Social factors such as resistance to change, skepticism toward external programs, and fragmented landholdings also reduce collective action. Overcoming these barriers demands financial incentives, farmer training, reliable monitoring systems, and strong policy frameworks to transform carbon farming from an ambitious concept into an effective, scalable climate solution.

CONCLUSION

Carbon farming stands out as a transformative approach to mitigate climate change while supporting agricultural sustainability. By integrating practices such as conservation tillage, agroforestry, cover cropping, and livestock integration, it enhances soil fertility, biodiversity, and water retention, while simultaneously sequestering atmospheric carbon. Technological innovations, including remote sensing, AI, and blockchain, further strengthen its potential by improving measurement, transparency, and scalability. However, challenges like high costs, knowledge gaps, and policy limitations must be addressed through supportive frameworks, incentives, and farmer training. If effectively implemented, carbon farming can bridge local agricultural practices with global climate goals, creating resilient food systems and a sustainable, low-carbon future.

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GENETIC RESOURCES OF WEEDS: COLLECTION, CHARACTERIZATION, AND UTILIZATION

Abstract
Weeds are often seen as nothing more than unwanted plants that compete with crops, reduce yields, and increase production costs. But behind their troublesome nature lies an extraordinary reservoir of genetic diversity. These resilient plants possess traits that allow them to thrive under drought, heat, salinity, nutrient stress, heavy grazing, and even herbicide exposure. In an era when climate change and food security challenges are mounting, this "wild" genetic wealth is increasingly being recognized as a valuable asset. Understanding the genetic resources of weeds how they are collected, characterized, and used opens the door to innovations in crop improvement, ecological management, and sustainable agriculture.
Keywords: Weed genetic resources, collection, characterization, utilization and weed genetic diversity

Introduction

Weeds have evolved under intense natural and human-induced selection pressures for centuries (Chethan et al., 2022; Chander et al., 2023). They have adapted to disturbed soils, extreme climates, recurrent droughts, and changing cultivation practices (Chander et al., 2024; Kumar et al., 2025b; Mahawar et al., 2023). As a result, they often possess: Exceptional stress tolerance (heat, drought, salinity, flooding), efficient nutrient uptake systems, rapid reproductive strategies, resistance to pests, diseases, and herbicides, high genetic plasticity and adaptability (Kumar et al., 2025a; Sreekanth et al., 2025a; Sreekanth et al., 2024a). These traits make weeds not just strong competitors in the field but also valuable genetic donors for developing climate-resilient, stress-tolerant crops (Sreekanth et al., 2025b; Sreekanth et al., 2023; Sreekanth et al., 2024b). Scientists now increasingly turn to weed species to identify genes that may help crops survive harsh future environments (Sreekanth et al., 2025c).

Collection of weed genetic resources

Systematic collection is the first step toward exploring weed diversity. This involves identifying, documenting, and conserving weed populations from different agroecosystems before their genetic diversity is lost due to urbanization, weed control practices, or habitat destruction.

1. Field exploration and survey

Teams survey farms, roadsides, forest margins, fallows, and water bodies to locate diverse weed populations. They record: habitat type, soil characteristics, associated crops, climatic conditions, phenotypic traits (height, flowering time, pigmentation, etc.). This helps preserve the ecological context in which weeds have adapted.

2. Collection of seeds and vegetative material

Seeds are the primary material collected for long-term storage. For vegetatively propagated weeds (e.g., sedges or rhizomatous species), stems, tubers, or rhizomes may also be collected. To capture genetic variability, samples are gathered from: multiple plants within a population, populations across wide ecological zones, different seasons when relevant.

3. Documentation and passport data

Each collection is accompanied by "passport data" location coordinates, date, collector details, plant descriptors, and environmental notes. This information ensures future researchers can interpret genetic variation accurately.

4. Conservation in gene banks

Collected materials are stored in: seed banks (low-temperature, low-moisture storage), field gene banks (living collections), cryogenic repositories (for long-term conservation of vegetative tissues), national institutions such as ICAR-NBPGR in India and global hubs like CGIAR centers play a crucial role in conserving weed germplasm.

Characterization of weed genetic resources

Once collected, weeds undergo characterization the process of documenting their physical, biochemical, and genetic traits.

1. Morphological characterization: This involves studying visible traits such as: plant height and branching, leaf shape and color, seed morphology, flowering and seed set, growth habit and biomass. These descriptors help classify species, detect variants, and identify unique or adaptive traits.

2. Physiological and biochemical characterization

Weeds often possess efficient physiological mechanisms. Scientists assess: Photosynthetic efficiency (especially in C_4 weeds), water-use efficiency, nutrient uptake patterns, stress response mechanisms, secondary metabolites, such information provides clues to why weeds are often superior competitors (Naidu et al., 2024; Negi et al., 2024).

3. Molecular and genomic characterization

Advanced tools, including: DNA barcoding, genome sequencing, SNP markers, transcriptomics, epigenetic profiling, help uncover genetic diversity, population structure, evolutionary patterns, and genes linked to stress tolerance or herbicide resistance.

4. Screening for agronomically important traits

Weeds are evaluated for traits such as: Drought and heat tolerance, resistance to insects and pathogens, salinity and flood tolerance, herbicide resistance, rapid germination or seed dormancy mechanisms. This screening helps identify genes that may be transferred to crop species or used in breeding programs (Pasala et al., 2025; Pawar et al., 2022; Roy et al., 2023).

Utilization of weed genetic resources

The true value of weed genetic resources lies in how they can be used to support agriculture, biodiversity conservation, and climate adaptation.

1. Crop improvement and breeding

Weeds often harbor genes that crops may have lost during domestication. These useful traits can be incorporated into crops through: conventional breeding (using wild crop relatives and weedy lines), genetic engineering, genome editing tools like CRISPR/Cas systems. For example: Amaranthus species possess high nutritional quality and drought tolerance, useful for improving quinoa or spinach. Echinochloa species show strong stress resilience, offering insights for improving rice adaptability. Wild Brassica weeds contribute valuable disease-resistance genes.

2. Understanding and managing herbicide resistance

Weeds provide model systems to study: target-site mutations, enhanced metabolism via cytochrome P450s, gene amplification and epigenetic regulation. Insights gained from these mechanisms help design better herbicides and resistance management strategies.

3. Ecological and evolutionary studies

Weeds reflect rapid evolution in response to human activities. Studying them helps understand: Adaptation under climate change, invasive species evolution, gene flow between crops and weeds, weed–soil–microbe interactions. These findings guide sustainable ecosystem management (Roy et al., 2022; Sondhia et al., 2023; Sondhia et al., 2024).

4. Bioprospecting for useful compounds

Some weeds produce unique metabolites with: medicinal properties, pest-control potential, industrial applications. For instance, *Parthenium hysterophorus* contains sesquiterpene lactones with pharmaceutical importance.

5. Strengthening climate resilience in agriculture

As extreme temperatures, CO_2 levels, and drought events increase, weeds offer a genetic "toolbox" that can help crops adapt. Their traits support: heat resilience, water-use efficiency, rapid recovery after stress, pest and pathogen resistance. Harnessing these traits is key to future-proofing agriculture.

Challenges in using weed genetic resources

While promising, integrating weed genetic resources into mainstream research faces challenges: Difficulty in controlling weeds' aggressive traits during breeding, risk of gene flow from crops back to weeds, limited genomic information for many species, underrepresentation of weeds in global gene banks, social perception of weeds as "useless" or "problematic". Overcoming these barriers requires coordinated research, policy support, and awareness programs.

Conclusion

Weeds may be unwanted guests in farmers' fields, but they are ecological survivors with remarkable genetic capabilities. Their ability to flourish under stress, resist herbicides, and adapt to changing environments makes them invaluable natural resources. By systematically collecting, characterizing, and utilizing the genetic diversity of weeds, scientists can tap into a powerful reservoir of traits that support crop improvement, environmental sustainability, and climate resilience. As agriculture moves toward a future shaped by climate uncertainty and rising global food demand, the genetic resources of weeds once ignored now stand as crucial allies in safeguarding global food security.

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SMART BREEDING FOR NEXT-GENERATION CROP IMPROVEMENT

Introduction

Smart breeding is a holistic transformation refers to the convergence of classical plant breeding with genomics, phenomics, marker-assisted breeding, genome editing, digital phenotyping, and artificial intelligence (AI) and computational tools. It seeks to enhance precision and efficiency in crop improvement by integrating high-throughput data from genomes, transcriptomes, proteomes, metabolomes, and field environments. Conventional plant breeding, the foundation of agricultural innovation mostly relies on visual selection and phenotype-based evaluation and its success depends heavily on natural variation in the population. Breeding cycles are long and trait improvement is slower for polygenic or complex traits and often spanning a decade or more for major crops like wheat or rice where as smart breeding is an advanced technology which combines genomic data, AI models, phenomics, and genome editing to guide selection as the breeding decisions are data-driven, reduces breeding cycles by 30–50% and capable of multi-trait optimization, such as yield, stress tolerance, and quality simultaneously, accelerating the release of improved varieties. The detail comparison between conventional breeding and smart breeding are given in table-1. A smart breeding platform model (Li et al. 2024) given in figure-1 describe about the processes and steps in data collection and analysis. The concept of smart breeding greatly depends on generating large breeding populations, efficient high throughput phenotyping, big data management tools and downstream molecular techniques to tackle the vulnerability of crops to changing climate.

The first phase of modernization in breeding came through molecular marker-assisted selection (MAS) enabling the indirect selection of traits based on DNA markers linked to genes of interest. Subsequently**,** genomic selection (GS) expanded the potential by using genome-wide marker data to predict the breeding value of individuals, even for complex quantitative traits. Then the phase *smart breeding* extends it by including AI-based prediction models, digital field phenotyping, remote sensing, and real-time data analytics. (Cai et al.2025). The CGIAR Excellence in Breeding (EiB) platform has been instrumental in integrating genomic selection, data management, and high-throughput phenotyping in breeding approaches. The International Rice Research Institute (IRRI) and International Maize and Wheat Improvement Center (CIMMYT) have pioneered digital breeding tools that combine AI-powered genomic prediction with climate modeling to develop resilient crop varieties. In India, the ICAR– Advanced Supercomputing Hub for Omics Knowledge in Agriculture (ASHOKA) promotes genomic data integration for crop improvement.

Tools and technologies used in smart breeding

The emergence of smart breeding has been facilitated by rapid technological advancements in multiple domains:

1. ***Marker-assisted selection (MAS)****:* Uses molecular markers to identify and select for desirable genes/traits, which is faster and more precise than traditional selection methods. Suitable for stress tolerance varietal development.
2. ***Genomic Selection (GS):*** Unlike MAS, which focuses on a few markers, GS evaluates the entire genome simultaneously. By building prediction models from large datasets, GS estimates breeding values even for lines not yet tested in the field. It has proven especially useful in crops like wheat, maize, and soybean.
3. ***Genome Editing Tools:*** Zinc-finger nucleases (ZFNs), Transcription activator-like effector nucleases (TALENs), Clustered regularly interspaced short palindromic repeats (CRISPR)-associated proteins (Cas), and base editing tools have revolutionized the way of modifying targeted genes. Among these gene editing tools, the popular one i.e. CRISPR allows most precise edits in plant genomes such as knocking out susceptibility genes in rice to confer disease resistance or modifying gluten proteins in wheat to make it safe for celiac patients. CRISPR/Cas systems have transformed functional genomics and precision breeding by enabling targeted, efficient, and heritable modifications in plant genomes. It is useful for faster development of new varieties by validating gene-trait associations for stress tolerance, disease resistance and quality trait improvement.
4. ***Next-Generation Sequencing (NGS):*** Affordable, high-throughput sequencing technologies have made it possible to decode entire plant genomes quickly and at low cost. This has led to the development of extensive genomic databases for major crops, enabling genome-wide association studies (GWAS) and genomic selection models (Zhang et al, 2023).
5. ***High-Throughput Phenotyping (HTP):*** Measures plant traits rapidly using sensors and imaging. Digital imaging, drones and sensors allow continuous real-time data, non-destructive measurement of plant traits at field scale. The integration of multispectral, hyperspectral, and thermal imaging provides insights into crop physiology, Canopy temperature, growth rate, stress response, root architecture and yield potential (Zhang and Zhang , 2018)
6. ***Multi-Omics Integration****:* Combines genomics, transcriptomics, metabolomics, proteomics and applied in trait dissection for comprehensive understanding of complex traits, gene discovery, metabolic pathway analysis (Zhang et al. 2022)
7. ***Big Data and Cloud Computing:*** Breeding programs now handle terabytes of multi-omics and environmental data. Cloud-based analytical platforms facilitate data integration, collaborative analysis, and real-time visualization, ensuring scalability and accessibility.
8. ***Artificial intelligence:*** AI capable of handling large, complex datasets, analyzes these complex datasets efficiently to predict breeding outcomes and hybrid performance. It also analyze genotype–environment interactions, climate adaptation and optimize cross designs. AI models learn continuously from new data, improving prediction accuracy over time. AI has revolutionized data interpretation by identifying subtle,

Table-1. Comparison of Traditional breeding and Smart breeding		
Characteristics	**Traditional breeding**	**Smart breeding**
Selection Basis	Phenotypic traits observed in field	Genotypic, multi-omics, and predictive models
Development Speed	Slower; 10–15 years	Comparatively faster; 4–6 years
Precision	Limited; environmental influence on phenotype	High precision using genome-wide markers, CRISPR editing and AI predictions
Polygenic traits	difficult to manage	Can handle complex polygenic traits
Abiotic & biotic Stress Improvement	Slower ; dependent on natural variation	Targeted improvement using QTLs, genome editing and predictive analytics
Data usage	Minimal; mainly observational records	Heavy reliance on big data i.e. omics and environmental data
Technology dependency	Low; simple breeding tools	High; requires bioinformatics, AI, genome editing, and omics data
Predictive capability	Low; outcomes largely empirical	High; AI models predict performance under diverse environmental conditions
Sustainability & efficiency	Resource-intensive; may require repeated field trials	Efficient, resource-smart, reduces input dependency, environmentally friendly

9. non-linear relationships that traditional statistical models may overlook (Xu et.al. 2022).
10. ***Speed breeding**:* It utilizes controlled environments to significantly shorten the time needed to grow crops, allowing for multiple generations per year (Watson et al.2018)

Benefits of smart breeding

Faster development: It significantly reduces the time for development of a new varieties.

Increased precision: It allows breeders to target specific genetic traits with greater accuracy.

Climate resilience: It is a crucial tool for development of abiotic stress tolerant varieties in different food and fiber crops that can withstand in frequent fluctuating climate condition.

Improved yield and quality: It helps in genetic improvement of crops and development of desirable genotypes that are more resistant to diseases, require fewer inputs, and have higher yields. Biofortified crops address micronutrient deficiencies and improve public health.

Multi-Trait and Multi-Stress Optimization: ***Future breeding pipelines will focus on simultaneous improvement of multiple traits i.e. yield, stress tolerance, nutritional content, and quality. AI models will predict complex trait interactions and optimize cross-design strategies.***

Real time decision support: The integration of AI, genomics, phenomics and environmental modeling provides real-time decision support.

Economic Development: High-performing varieties increase farm income and support rural livelihoods.

Application in crop improvement

Smart breeding has delivered measurable

advances across major crops and agro-ecological contexts are as follows. The smart breeding applications for improvement of different crop is give in table-2.

Yield Stability and Productivity: Genomic selection and AI-driven prediction have reduced breeding cycles by 30–50%, producing varieties with enhanced yield stability under diverse environmental conditions.

Abiotic Stress Tolerance: Drought-, heat-, and salinity-tolerant varieties of maize, wheat, rice, and pulses have been developed using multi-omics-guided selection. CRISPR-mediated gene editing has accelerated the development of stress-resilient lines with precise trait modifications.

***Biotic Stress Resistance*:** Disease- and pest-resistant crops benefit from pyramiding resistance genes using marker-assisted selection and genome editing. AI-driven screening of germplasm has enhanced identification of durable resistance alleles.

***Nutritional and Quality Improvement*:** Biofortified wheat, rice, maize, and pulses address micronutrient deficiencies. Genome editing has improved flavor, shelf life, and starch composition in horticultural crops.

Sustainability and Climate Resilience: Crops with improved resource-use efficiency reduce fertilizer and water dependency. Smart breeding contributes to carbon sequestration and environmentally sustainable farming practices.

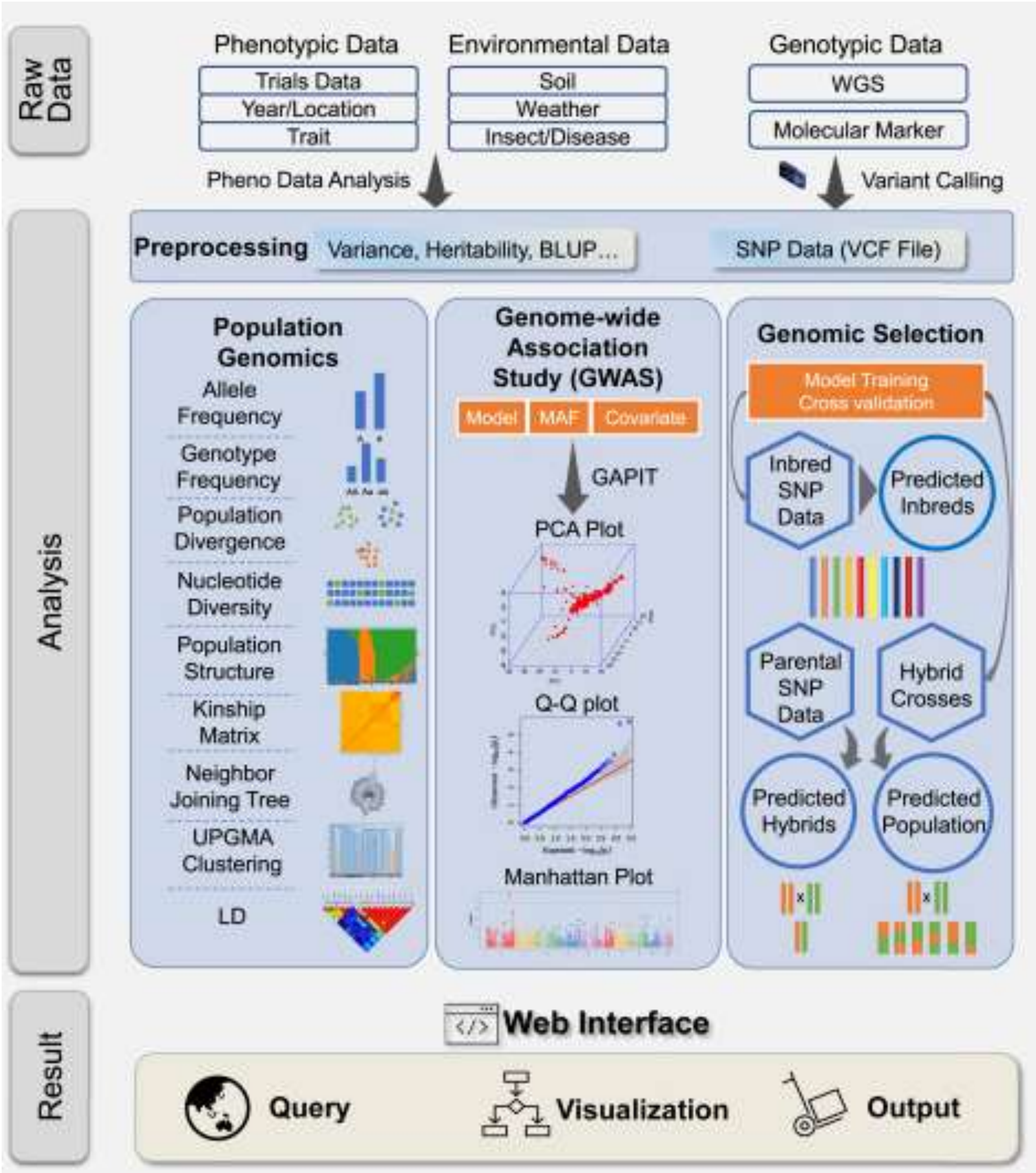
Conclusion

Smart breeding is not only a tool for crop improvement but a cornerstone of sustainable agriculture in the 21st century. It embodies the fusion of biological insight, technological innovation, and societal responsibility, charting a path toward a resilient, equitable, and food-secure future. However, the success of smart breeding depends on policy support, ethical oversight, and equitable access**,** ensuring that technological advancements benefit both farmers and society at large.

Table 2: Smart breeding applications in crop improvement

Crop	Trait targeted	Smart breeding approach	Achievement
Wheat	Heat & drought tolerance	Genomic selection + AI prediction	yield increase under stress, shorter breeding cycles
Rice	Salinity tolerance	Marker-assisted backcrossing + CRISPR editing	Salt-tolerant varieties suitable for coastal regions
Maize	Drought tolerance	Genomic selection + high-throughput phenotyping	Increase yield under drought conditions
Pearl Millet	Drought & heat tolerance	Multi-omics integration + genomic selection	Resource-efficient and climate-resilient variety development
Soybean	Pest resistance	Genomics + AI-assisted screening	Novel resistance alleles identified, improved durability
Tomato	Shelf-life & quality	CRISPR editing of ripening genes	Extended shelf life, improved sweetness and texture
Banana	Nutritional quality	Genome editing & metabolomics	Enhanced micronutrient content, improved disease tolerance

Fig-1. Smart Breeding Platform (Li et al. 2024).
(WGS: whole-genome sequencing; BLUP: best linear unbiased prediction; SNP: single nucleotide polymorphism; UPGMA: unweighted pair group method with arithmetic mean; LD: linkage disequilibrium; PCA: principal component analysis)



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SYSTEM OF CROP INTENSIFICATION- A PROFITABLE APPROACH TO FARMING

Abstract

The intense use of chemicals, excessive irrigation, monocropping, and excessive soil tillage that characterise modern agriculture demand extremely high input costs that farmers with limited resources cannot afford. By altering crop management techniques, the system of crop intensification approach aims to increase output while using less land, labour, capital, and water—a long-standing and universal goal—rather than just increasing output from a given amount of inputs. This article examines the principles of the System of Crop Intensification (SCI) for a profitable and sustainable farming method in different crops like Rice, Wheat, Sugarcane, Finger millet, and Mustard.

Key words: system, intensification, crop, sustainable, profitable

1. Introduction

System of crop intensification approach seeks not just a long-standing and universal goal for getting more output from a given amount of inputs, but aims to achieve higher output with limited use of inputs by making modifications in crop management practices.

System of crop intensification practices enables to trigger biological processes and potentials that are present and available with crop plants and within the soil system that support them by altering the traditional practices of crop, soil, water and nutrient management.

2. Principles of System of Crop Intensification

- **Reduced seed rate and use of good quality seeds** for better crop establishment, vigorous initial growth and extensive root system.
- **Early transplanting for better growth**. Seedlings are transplanted early which helps them to establish faster and grow better.
- **Providing wide spacing to plants** for minimizing competition between plants for available nutrients, water, air and sunlight necessary for better growth. This enables each plant to attain close to its maximum genetic potential. It promotes vigorous crop growth with 4–5 times increase in number of tillers.

- **Keeping the top soil around the plants well-aerated** through appropriate implements or tools so that soil system can freely exchange air and water. Usually done as part of interculture or weeding operation typically with hand-weeded with special tools like rotary weeders, cono-weeders, cycle weeders or Japanese paddy weeders, which reduces the weed menace.
- **Irrigation facilities should be used sparingly**, avoiding the soil from becoming waterlogged and hypoxic. A balanced proportion of air and water in the soil is critical for plants growth and health, sustaining better root system. Instead of continuous flooding, SCI promotes alternate wetting and drying (AWD) practice, which saves water and reduces methane emissions.
- **Amending the soil with organic matter** such as FYM (farmyard manure), vermicompost, biofertilizers etc., as much as possible, to enhance its fertility and soil structure and to support the soil biota. Organic matter content can enhance the water holding capacity of the soil.
- **Reducing use of inorganic fertilizers and plant protection chemical to** minimize environmental and health hazards, and adverse impacts on beneficial soil organisms.

3. System of Crop Intensification in different crops

System of crop intensification principles is popular for variety of crops which include system of rice intensification (SRI), System of wheat intensification (SWI), Sustainable sugarcane initiative (SSI), System of mustard intensification (SMI) and System of finger millet intensification (SFMI).

3.1 System of Rice Intensification (SRI)

The key physiological mechanism behind the system of rice intensification (SRI) is to provide optimal growing conditions to individual rice plants so that tillering is maximized and phyllochrons are shortened, which is believed to accelerate growth rates. It was also observed that tiller mortality is reduced. Furthermore, intermittent irrigation is believed to improve oxygen supply to rice roots, thereby decreasing aerenchyma formation and causing a stronger, healthier root system with potential advantages for nutrient uptake.

Major SRI principles include: raising seedlings in carefully managed nurseries; careful transplanting of single, young (8–15 days old) seedlings; wider plant spacing (starting at 25 cm × 25 cm, but going up to 50 cm × 50 cm); intermittent irrigation to avoid permanent flooding during the vegetative growth phase; addition of nutrients to the soil, preferably in organic forms such as compost instead of chemical fertilizers; and intensive manual or mechanical weed control without herbicide use.

3.2 System of finger millet intensification (SFMI)

The idea of system of finger millet intensification (SFMI) is traditional concept. It has been practiced with different names (Guli/Guni/Netti) since last 40 years by the farmers of Haveri district of Karnataka with some location-wise modifications and variations**.** SFMI aims at establishment of single, young (12 days old) and healthy seedlings for optimum root and shoot growth, with wider spacing (25cm X 25 cm) for effective utilization of space, light, nutrients and water, etc., improvement of soil health enriching through organic matter, aeration as well as weed control by cycle weeder, reduced use of water for moistening the soil without creating hypoxic condition and using organic formulations like *Jibamruta* to control insect pests and diseases. All these agronomic practices can result in improved the crop yield and quality.

3.3 Sustainable sugarcane initiative (SSI)

Similar to SRI in rice, sustainable sugarcane initiative(SSI) is yet another practical approach to sugarcane production which is based on the principles of 'more with less' in agriculture. SSI is more advantageous than the conventional practices as it enables to provide benefits: 20-30% more yield, saving of water (30-40%), fertilizer (25-30%), labour (40-45%) and seed material (60-70%), intercultural operations can be carried out easily due to wider spacing.

Raising nursery using single-budded chips; transplanting young seedlings (25 to 35 days old); maintaining wide spacing (150 cm × 60 cm) in the main field (conventional spacing is 45 cm × 75 cm), which reduces the seed requirement by 75% from 48,000 to 5,000 single-budded chips per acre and providing sufficient moisture but avoiding inundation of water, whereby 40% of water is saved (conventionally, flooding is practised); encouraging organic methods of nutrient management and plant-protection.

3.4 System of wheat intensification (SWI)

System of Wheat Intensification (SWI) is a new wheat cultivation technique which demands to maintain wider plant spacing. This kind of sowing with proper plant density allows for sufficient aeration, moisture, sunlight and nutrient availability leading to proper root system development from the early stage of crop growth. Comparison between conventional and SWI methods is presented below-

S.No	Conventional Cultivation	SWI Method
1	Seed requirement is 100-125 kg/ha	Seed requirement is 20-25 kg/ha
2	Closer spacing (20-25 cm x 8-10 cm)	Wider spacing (20-50 cm x 20 cm)
3	Hand weeding or application of herbicides is done	Weeding is done by cono weeder.
4	The number of irrigations is 2-4	The number of irrigations is 4-5

Source: PRADAN (2012)

3.5 System of mustard intensification (SMI)

System of mustard intensification is the system of transplanting mustard seedlings with wide spacing which is similar to the system of rice intensification. SMI is described as follows-

S.No	Conventional Cultivation	SMI Method
1	Seed requirement per ha is 5.5 kg	Seed requirement per ha is 125-300 g
2	Sowing is done through broadcasting	Transplanting done
3	No proper spacing is maintained	Spacing of 30 cm x 30 cm to 75 cm x 75 cm
4	No. of irrigation is about 2-3	No. of irrigation is about 4-5
5	Yield per acre is 0.4-0.8 tonnes	Yield per acre is about 1.2 to 2 tonnes

Source: Training Manual on Cultivating Rapeseed/Mustard with SRI principles, PRADAN (2012)

4. Conclusion

System of crop intensification holds good prospect in enhancing the productivity of crops over conventional method. SCI is an improved option as it is eco-friendly and revives soil health as well as ensures vigorous crop growth and yield. SCI aims to improve the productivity, food security and resilience to climate change by altering the traditional practices of crop, soil, water and nutrient management. Therefore, classical crop cultivation practices needs to be replaced by system of crop intensification for more profitable and sustainable agriculture.

5. Limitations

Poor adoption and confinement to limited areas requires organizational/individual support as well as strong extension/awareness programmes.

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MUSHROOM FARMING: A GROWING INDUSTRY WITH A BRIGHT FUTURE

Introduction

In a world grappling with the dual challenges of food security and sustainable agriculture, a quiet revolution is taking root—beneath compost beds, in climate-controlled rooms, and even in urban basements. This revolution is none other than mushroom farming, a fast-growing industry that combines nutrition, entrepreneurship, and environmental sustainability.

From humble roadside stalls to gourmet kitchens, mushrooms have made their way into mainstream diets, especially among health-conscious consumers. With global demand rising steadily and production techniques becoming more accessible, mushroom cultivation is no longer just a side venture—it's an emerging agri-business opportunity with serious potential.

Why Mushroom Farming?

Mushroom farming is gaining momentum worldwide for several reasons. First, it is space-efficient and low-cost compared to conventional agriculture. Mushrooms don't require large tracts of land or fertile soil. They can be grown indoors, on vertical shelves, or even in recycled containers—making them ideal for small farmers, urban gardeners, and start-up entrepreneurs. Second, mushrooms can be cultivated on agricultural waste materials like straw, sawdust, and coffee grounds, turning farm residues into profit. This aspect gives mushroom farming a sustainable edge, as it supports the circular economy and helps manage organic waste. Third, mushrooms mature quickly—most edible varieties complete their lifecycle within three to six weeks. This short cultivation cycle means more harvests per year and a faster return on investment. Lastly, growing awareness about the nutritional and medicinal benefits of mushrooms has sparked new consumer demand, opening up domestic and export markets. In many parts of Asia, Europe, and North America, gourmet mushrooms are commanding premium prices.

Types of Edible Mushrooms Cultivated

Globally, more than 2000 mushroom species are considered edible, but only a select few are commercially cultivated. Each variety comes with its own growing conditions, nutritional profile, and market niche.

1. **Paddy straw mushroom (*Volvariella volvacea*)**

It thrives in tropical/subtropical climates.
• Cultivation: Uses paddy straw as substrate (10–15 kg straw per bed). Ideal growth conditions: temp ~25–35 °C, relative humidity ~75–80%.
• Growth cycle: Very fast — the total crop cycle (from spawn to harvest) is about 3–4 weeks under favourable conditions.
• Nutritional value: It has good protein, fibre, ash content, and essential amino acids.
• Sustainability: Since it grows on paddy straw (an agricultural residue), cultivation helps repurpose waste.

2. Button Mushroom (*Agaricus bisporus*):

This is the most commonly consumed mushroom worldwide. It thrives in cooler temperatures (15–18°C) and is grown on composted manure substrates. It has a mild flavour and is widely used in salads, curries, pizzas, and soups.

3. Oyster Mushroom (*Pleurotus* spp.):

Known for its rapid growth and tolerance to a range of climates, oyster mushroom is ideal for beginners. It grows on straw or sawdust and is available in various shades—white, grey, pink, and yellow. It has a soft texture and subtle taste.

4. Shiitake (*Lentinula edodes*):

A popular variety in Asian cuisine, shiitake is cultivated on hardwood logs or sawdust blocks. It has a meaty texture and is prized for its umami flavour and medicinal properties.

5. Milky Mushroom (*Calocybe indica*):

Native to India, milky mushroom grows well in tropical climates. It has a longer shelf life and is gaining popularity for its robust taste and texture.

6. Enoki, Maitake, and Lion's Mane:

These are speciality or medicinal mushrooms that cater to gourmet chefs and health-conscious consumers. Though they require more careful handling and climate control, they offer high returns in niche markets.

Edible and Poisonous Mushrooms

When grown properly, edible mushrooms (such as button, oyster, milky, and paddy straw) are safe, widely grown, and have a well-known biology.

Poisonous mushrooms comprise a variety of wild species, they may contain harmful substances, and misidentification can result in poisoning.

Safety Warning: Never Use Unknown Wild Mushrooms for Consumption

Both edible and toxic mushrooms can be found in nature, particularly in woods and other wild areas. Stress the customary safety warning to avoid mushroom poisoning: "Never consume mushrooms collected from unknown sources without expert identification." Additionally, emphasize that commercially grown mushrooms are safer due to their controlled spawn and substrate, which greatly reduces risk.

Medicinal mushrooms and their benefits

Mushroom	Scientific name	Benefits
Reishi	*Ganoderma lucidum*	Immune modulation, anti-inflammatory, potentially supports stress reduction
Cordyceps	*Cordyceps sinensis* or *C. militaris*	Believed to boost energy, stamina, and possibly improve oxygen utilisation
Lion`s Mane	*Hericium erinaceus*	Cognitive support: memory, focus, possibly nerve regeneration
Turkey Tail	*Trametes versicolor*	Boost immune system (beta glucans), gut health benefits.

Health and Nutritional Benefits of Mushrooms

Mushrooms are often called the "vegetarian meat" because of their rich umami flavour and high-quality protein. But their value goes far beyond taste. Nutritionally, mushrooms are:

- Low in calories and fat
- Rich in dietary fibre, B-complex vitamins (like niacin, riboflavin, and folate)
- Packed with minerals such as selenium, copper, potassium, and phosphorus
- Loaded with antioxidants like ergothioneine and glutathione

Some mushrooms, like shiitake and maitake, contain beta-glucans—compounds that enhance immune function. Lion's mane is being studied for its role in cognitive health and nerve regeneration. Others have anti-inflammatory, antiviral, and anti-cancer properties, making them highly valued in both traditional and modern medicine. In countries like Japan and South Korea, mushrooms are regularly used in nutraceuticals and functional foods. This growing global awareness is pushing mushrooms to the forefront of health-focused agriculture.

Economic Potential and Income Opportunities

Mushroom farming is considered one of the most profitable agro-enterprises per square foot. For example, a 100-square-foot unit producing oyster mushrooms can yield up to 200–250 kg in a 30–40 day cycle. At a selling price of ₹120–150 per kg (in India), this translates to ₹25,000–30,000 per month, after basic expenses. Larger farms producing button or shiitake mushrooms can scale operations and cater to retail chains, hotels, and exporters. Some high-end gourmet mushrooms like lion's mane and maitake sell for ₹500–800 per kg in health stores and online markets. Additionally, by-products like spent mushroom substrate can be sold as organic compost or used in vermiculture. Entrepreneurs can also earn by setting up spawn labs, offering training workshops, or marketing value-added products like mushroom chips, pickles, powders, and ready-to-cook kits. With low water usage, fast returns, and year-round production, mushroom farming offers an attractive livelihood opportunity—especially for women, youth, and marginal farmers.

Basic Requirements and Setup for Mushroom Cultivation

One of the main attractions of mushroom farming is its **low entry barrier**. With some basic knowledge, a modest investment, and proper hygiene, almost anyone can start a mushroom unit.

The essential components of a mushroom farm include:

1. Growing Space:

This could be a shed, room, or any clean, well-ventilated space with proper insulation. Humidity and temperature control are key to success.

2. Substrate Preparation:

Substrate is the growing medium. For oyster mushrooms, straw is chopped, soaked, pasteurized, and packed into plastic bags. For button mushrooms, a compost made from wheat straw and manure is used.

3. Spawn Inoculation:

Spawn is the seed-like material used to start mushroom growth. It is mixed into the substrate and kept in dark incubation conditions for a few weeks to allow mycelium (fungal network) to colonize the medium.

4. Fruiting Conditions:

Once colonized, the bags are exposed to light, humidity (80–90%), and fresh air to trigger fruiting. This stage lasts 7–15 days depending on the variety.

5. Harvest and Post-Harvest Handling:

Mushrooms are picked at their prime and sold fresh or dried. Clean packaging, cold storage, and prompt delivery help maintain quality and shelf life.

Challenges Faced by Mushroom Growers

Despite its promise, mushroom farming does come with a set of challenges.

1. Perishability:

Fresh mushrooms have a short shelf life (1–3 days without refrigeration). Lack of cold storage and transportation infrastructure can lead to post-harvest losses.

2. Contamination Risks:

Mushrooms are highly sensitive to hygiene. Contaminants like molds or bacteria can ruin entire batches if cleanliness is not maintained.

3. Market Access:

In some areas, local demand is still developing, and farmers may struggle to find consistent buyers or fair prices. Middlemen often take a large share of profits.

4. Climate Sensitivity:

Many mushroom species require precise temperature and humidity. Farmers in tropical areas may need to invest in climate control, increasing operational costs.

5. Lack of Awareness and Training:

In rural areas, knowledge about spawn quality, substrate handling, and disease control is still limited. This results in poor yields and discouragement.

Recent Innovations and Technological Advancements

Technology is transforming mushroom cultivation into a high-tech business. Climate-controlled growing chambers, automated misting systems, and data-driven monitoring apps are helping farmers maintain ideal conditions and increase productivity.

Mushroom vertical farming is gaining popularity in urban spaces. These systems stack multiple trays in modular units, allowing cultivation in warehouses, containers, or basements using minimal space.

Spawn production labs are now using

sterilized grain spawn with higher success rates. Innovations in packaging, dehydration, and preservation are extending shelf life and reducing waste.

On the research front, scientists are exploring CRISPR gene editing to enhance mushroom shelf life and disease resistance. Startups are also experimenting with mushroom-based leather, packaging materials, and meat alternatives, tapping into sustainability-driven markets.

Government Support and Training Programs

Recognizing its potential, several governments and NGOs are actively promoting mushroom farming. In India, the National Horticulture Board (NHB) and National Medicinal Plants Board (NMPB) offer subsidies for mushroom units and training. The Indian Council of Agricultural Research (ICAR), Agricultural Universities, Agricultural Colleges, Krishi Vigyan Kendras (KVKs), Agricultural and Horticultural departments and leading mushroom growers conduct hands-on workshops and spawn distribution. Many self-help groups and women's collectives have embraced mushroom farming as part of rural income generation and nutritional security programs.

Subsidy

Government support programs exist. For instance, Bihar offers a 50% subsidy (up to ₹10 lakh) for growing mushrooms. According to the agri-entrepreneur portal "How to Start Mushroom Farming in India," the National Horticulture Board (NHB) offers credit-linked subsidies for mushroom houses, polyhouses, and sterilization units under the Ministry of Agriculture's Mission for Integrated Development of Horticulture (MIDH).

Cost-profit analyses demonstrate the viability of small-scale production and the revenue was computed assuming ₹300/kg of mushrooms.

Mushroom Selling Prices Increased – Recent Price Trends

According to a recent news-report, during the Kartika month (a period in some regions when many follow a sattvic diet), demand for mushrooms including paddy straw and button mushrooms surged, pushing retail prices up to ₹250–₹400 per kg.

According to a mandi/market listing (Commodity Online), mushroom prices vary widely depending on region: e.g., one market shows ₹200/kg, another as low as ₹100/kg.

For button mushroom specifically, historically average market prices are around ₹250–₹300/kg (source from a mushroom farming cost-profit analysis).

Market Growth: The overall Indian mushroom market is expected to grow at a CAGR of ~12.70% from 2024 to 2030.

Demand Increased

Demand is being driven by the growing interest in "functional" or medicinal mushrooms (such as reishi, cordyceps, lion's mane, and turkey tail). Market report: The Indian mushroom market is already large (USD 1.18 billion in 2023) and is expected to grow strongly. Local demand example: In some city markets (like Ranchi), the demand for indigenous mushrooms.

Selling Channels: Local Markets, Hotels, Hostels, etc.

Local markets: A lot of mushroom producers sell their products at farmer markets or vegetable mandis, and local customers are starting to accept mushrooms.

Institutional supply: There is a significant chance of providing hotels, restaurants, and other hospitality establishments due to rising demand. The gourmet appeal and nutritious benefits of mushrooms make them appealing.

Regular supply systems: Hotel chains, hostels, and catering establishments benefit from growers' ability to maintain a steadier supply through controlled cultivation.

Value-addition: To serve hotels and hostels that desire a long shelf life, mushrooms can be partially processed (cleaned, packaged, or even dried).

Conclusion

Mushroom farming is no longer an obscure or experimental venture—it is a thriving, science-backed industry with immense scope. From the backyard farmer to tech-savvy entrepreneurs, from health-conscious consumers to gourmet chefs, the mushroom sector is attracting diverse stakeholders.

With the right knowledge, infrastructure, and market linkages, mushrooms can serve as a source of nutrition, livelihood, sustainability, and innovation all in one. As the world moves toward climate-smart agriculture and healthier diets, mushrooms are well-positioned to take centre stage.

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GREEN MANURING: CONCEPTS, SOIL IMPACTS AND AGRONOMIC APPLICATIONS

Abstract

Green manuring is an environmentally sustainable soil management practice that involves growing or adding fresh plant biomass to the soil to enhance nutrient availability, organic matter content and soil physical, chemical and biological properties. Leguminous species are commonly used due to their ability to fix atmospheric nitrogen through symbiosis with Rhizobium. This review summarizes the principles, crop characteristics, agronomy, methods of incorporation, benefits, limitations and the effects of green manures on degraded, saline and sodic soils. Practical guidelines for effective implementation of green manuring in various cropping systems are also provided.

Key words: Green manuring, legumes, sustainable, symbiosis

1. Introduction

Green manure refers to fresh, undecomposed plant material incorporated into soil to improve soil fertility and productivity. Green manuring is the practice of growing specific crops—predominantly legumes either within the field (in-situ green manuring) or collecting plant biomass from outside sources (green leaf manuring) for incorporation. Leguminous green manure crops enhance soil nitrogen through symbiotic nitrogen fixation, contributing substantial quantities of biologically fixed nitrogen to succeeding crops. Green manures are incorporated before they become woody to ensure rapid decomposition and release of nutrients. Two major approaches are used:

1.1 Green manuring in-situ

This involves growing green manure crops directly in the field and incorporating them after sufficient vegetative growth. Examples include sunhemp, dhaincha, pillipesara, greengram, and cluster bean. Phosphatic fertilizers enhance nodulation and nitrogen fixation, contributing to nutrient availability for subsequent crops.

1.2 Green leaf manuring

Green leaves and twigs from trees, shrubs and herbs are collected from bunds, forests, and wastelands and incorporated into the field. Common species includes neem, mahua, glyricidia, wild indigo, karanj, calotropis, subabul and avise.

2. Characteristics of an ideal green manure crop

1. Deep root system for nutrient mining from deeper soil layers
2. Low nutrient requirement
3. Rapid growth and high biomass production
4. Low water requirement
5. Easily decomposable biomass with low lignin content
6. Ability to fix atmospheric nitrogen (preferably legumes)
7. Not closely related to major crops (to avoid pest and disease carryover)
8. Ability to grow well in poor and degraded soils

3. Agronomy of some green manure crops:

Sunhemp: It is a quick growing green manure crop and gets ready for incorporation in about 45 days after sowing. The crop can produce about 8-12 tonnes of green biomass ha^{-1}. Seed requirement is 30 kg ha^{-1}.

Dhaincha: It is suitable for loamy and clayey soils. It is fairly resistant to drought as well as stagnation of water. It yields about 10-15 tonnes of green biomass ha^{-1}. Seed rate 20-25 kg ha^{-1}.

Cowpea: As this plant is easily decomposable and very well suited for green manure purpose. June- July are best suited for sowing. It requires very few inputs, as the plant's root nodules are able to fix atmospheric nitrogen.

***Sesbania rostrata*:** it is an aquatic leguminous crop which have nodules on both stem and roots. It is a tropical legume which thrives well under flooded and waterlogged conditions. The photoinsensitive nature of this crop restricts its usage in winter.

Greengram: As a legume plant, it is in symbiotic association with *Rhizobium* which enables it to fix atmospheric nitrogen 58–109 kg ha^{-1}. It can provide large amounts of biomass 7.16 t of biomass ha and nitrogen to the soil. It can be used as a cover crop before or after cereal crops in rotation, which makes a good green manure.

Wild indigo: This is a slow growing green manure crop and cattle do not prefer to graze it. It does not withstand water stagnation. It is hardy, drought resistant and suitable for summer fallows. Seed rate is 30 kg ha^{-1}. The seeds have a waxy impermeable seed coat and hence scarification is required to induce germination.

Glyricidia (*Glyricida maculata*):It is a fast growing, leguminous, medium sized, thornless tree which can substitute for *Leucaena leucocephala* (subabul) as a source of fodder, fuel wood and green manure, in hedges and living fences and as a shade tree in tea, coffee and cocoa plantations.

Pillipesara (*Phaseolus trilobus*): This is a dual purpose crop yielding good fodder for cattle and green manure for land. Though it does not produce bulky yield, it is capable of being cut twice or thrice before being ploughed into the field.

4. Stage of incorporation

The majority of the greenmanure crops require 6 to 8 weeks after sowing at which there is maximum green matter production and most succulent. The best stage of incorporation is the flowering stage of the crop. The plants used for green leaf manuring should be incorporated into the soil before they mature or attain the woody nature. Plants of very young nature also should not be incorporated as they will very easily decompose leaving little residues in the soil. Woody plants will decompose very slowly because of high lignin content. Hence better stage of incorporation of plants is either at the flowering stage or before they attain woody texture.

5. Methods of Application

5.1 In-Situ Green Manuring

Plants are cut or trampled and incorporated using a mould board plough, green manure trampler, or inter-cultivation equipment.

5.2 Green Leaf Manuring

Collected leaves are spread uniformly and mixed into the soil manually or with implements.

5.3 Intercropping Approach

Dhaincha and similar crops can be sown between widely spaced crops and incorporated through intercultivation.

6. Advantages

1. Enhances nutrient recycling from deeper soil layers
2. Stimulates microbial activity and organic matter decomposition
3. Produces organic acids that improve availability of P, Ca, Mg, K and Fe
4. Improves soil structure, porosity and water infiltration
5. Legumes fix 60–100 kg N ha^{-1} for subsequent crops
6. Increases yield of succeeding crops by 15–20%
7. Enhances solubility of phosphates and micronutrients
8. Reclaims sodic soils (e.g., dhaincha improves soil permeability)
9. Improves tilth and aggregate stability
10. Increases water-holding capacity
11. Acts as natural pest and nematode suppressants (e.g., Pongamia, neem)

7. Disadvantages

1. May bring deep-layer nutrients to the surface, causing imbalance
2. Occupies land for 45–50 days, potentially delaying main cropping
3. Improper decomposition may increase pest/disease incidence
4. Decomposition is slow in rainfed or moisture-deficit conditions
5. Requires adequate irrigation for proper biomass decomposition

8. Effects of green manures on soil

8.1 Salinity and Sodicity Remediation

Green manures reduce soil pH, electrical conductivity and exchangeable sodium percentage through organic acid production and enhanced Ca^{2+} availability. Dhaincha and sunhemp reduce Cl^{-}, SO_4^{2-}, HCO_3^{-} and CO_3^{2-} levels, improving soil health.

8.2 Soil Physical Properties

In sodic soils, organic inputs improve aggregate stability, reduce dispersion and enhance porosity. Microbial by-products such as mucilage and polysaccharides assist in binding clay particles.

8.3 Soil Organic Carbon

Green manuring increases soil organic carbon (SOC) through addition of biomass and improved aggregation. Enhanced CO_2 pressure dissolves $CaCO_3$, releasing Ca^{2+} that aids in flocculation and long-term carbon sequestration.

8.4 Biological Properties

Organic amendments enhance microbial biomass, enzymatic activity, and nutrient cycling even in saline/sodic environments. They buffer soil pH and support beneficial microbial communities.

9. Recommended Green Manuring Practices

1. Grow in any soil with adequate rainfall or irrigation
2. Use appropriate *Rhizobium* strains for legumes
3. Break hard seed coat (e.g., *Tephrosia*) by scarification or hot water treatment
4. Address nutrient deficiencies; P fertilizers enhance nodulation
5. Incorporate at flowering for maximum benefit
6. Incorporate 3–4 weeks before sowing main crop
7. Ensure proper soil moisture for decomposition
8. Use mechanical incorporation tools for large fields
9. Adopt green leaf manuring under limited moisture situations
10. Use intercropping with dhaincha where appropriate

10. Conclusion

Green manuring is a cost-effective, eco-friendly, and sustainable practice that significantly enhances soil fertility, structure, microbial activity, and crop productivity. Leguminous green manure crops play a vital role in nutrient cycling, especially nitrogen fixation. Their incorporation improves saline and sodic soils, increases soil organic carbon, and enhances long-term soil health. While certain limitations exist—such as land occupancy and moisture dependency—proper planning and management can maximize the benefits of green manuring across diverse cropping systems.

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DETERMINATION OF SAMPLING TECHNIQUES IN AGRICULTURAL EXTENSION RESEARCH

INTRODUCTION

Sampling is a fundamental aspect of research methodology that enables researchers to collect data from a subset of a population while making valid inferences about the entire population. In agricultural extension research, where populations are often dispersed across rural areas and farming communities are heterogeneous, selecting an appropriate sampling technique is critical. Effective sampling ensures that data accurately reflects farmers' practices, adoption of technologies, knowledge levels, and training needs. Poor sampling, on the other hand, can lead to biased findings, misinformed extension strategies, and ineffective policy recommendations. This article provides a detailed overview of the importance of sampling, factors influencing the choice of sampling technique, classification of methods, and a step-by-step guide for determining the most suitable approach in agricultural extension studies.

IMPORTANCE OF SAMPLING IN RESEARCH

Sampling is a critical component of research methodology because it allows researchers to gather information about a large population by studying a smaller, manageable subset. In most cases, it is neither feasible nor practical to study every member of a population due to constraints such as time, resources, and accessibility. By selecting a representative sample, researchers can draw meaningful conclusions and make generalizations about the entire population without the need for exhaustive data collection. The accuracy of the research findings depends heavily on the way the sample is chosen, making the determination of sampling techniques a vital step in the research process.

One of the primary reasons sampling is necessary is practicality. In large-scale studies, attempting to collect data from the entire population is often impossible. For example, a researcher aiming to understand dietary habits among adults in India cannot realistically survey over a billion people. Instead, selecting a representative sample allows the researcher to obtain valid insights while working within logistical constraints. Similarly, in international surveys or studies involving scattered populations, sampling becomes the only feasible approach to gather meaningful data in a reasonable time frame.

Sampling also offers significant cost advantages. Collecting data from every individual in a population can be prohibitively expensive, involving costs for travel, personnel, materials, and data processing. By studying a carefully chosen subset of the population, researchers can reduce expenses while still obtaining reliable results. For instance, a market research firm testing a new consumer product will survey a few hundred or thousand individuals rather than the entire target market, saving both time and resources while obtaining actionable insights.

Time efficiency is another crucial benefit of sampling. Research often needs to be completed within a limited period, and working with an entire population can delay the study considerably. A representative sample allows researchers to quickly collect, analyze, and interpret data, enabling timely decision-making. This is particularly important in fields like public health, marketing, and social sciences, where rapid analysis can inform policies, interventions, or business strategies.

Furthermore, working with a sample facilitates better management and analysis of data. Large datasets can be cumbersome and prone to errors during data entry, cleaning, and statistical analysis. A well-designed sample makes data handling more manageable, reducing the likelihood of mistakes and allowing for more precise statistical evaluation. This enables researchers to calculate measures of central tendency, variation, and confidence intervals effectively, which are essential for drawing valid conclusions about the population.

The choice of sampling technique significantly affects the quality of research outcomes. If the sample is poorly selected, it may introduce bias, making the findings unrepresentative of the population. For example, a study on agricultural practices conducted only in urban areas would fail to capture the realities of rural farming communities, leading to inaccurate conclusions. On the other hand, a carefully selected sample that reflects the diversity and characteristics of the population enhances the credibility and reliability of the research. Proper sampling also allows researchers to estimate potential errors and confidence levels, ensuring that the conclusions drawn are scientifically valid. In summary, sampling is an indispensable tool in research, providing a practical, cost-effective, and time-efficient way to study large populations. It enables researchers to make accurate generalizations while maintaining data manageability and analytical precision. The importance of sampling lies not only in its ability to reduce workload but also in its crucial role in ensuring that research findings are valid, reliable, and representative of the population under study. Without appropriate sampling, even well-designed research risks producing misleading or incorrect results.

FACTORS INFLUENCING THE CHOICE OF SAMPLING TECHNIQUE

Selecting an appropriate sampling technique is a critical decision in research, as it directly affects the representativeness, accuracy, and reliability of the study findings. Several factors must be carefully considered to ensure that the chosen method aligns with the objectives of the research and the nature of the population. Researchers need to evaluate the purpose of the study, the characteristics of the population, available resources, and the level of precision required before deciding on a sampling strategy.

One of the primary factors influencing the choice of sampling technique is the **research objective**. The goal of the study often determines the type of sampling method to be employed. For example, if the objective is to generalize findings to an entire population, probability sampling methods such as simple random sampling or stratified sampling are preferred, as they allow every individual an equal chance of selection and minimize bias. In contrast, if the research aims to explore a specific phenomenon in depth or study a unique subgroup, non-probability methods like purposive or snowball sampling may be more appropriate. Understanding whether the study is descriptive, exploratory, or experimental helps in selecting the most suitable sampling approach.

Another important consideration is the **size and nature of the population**. Homogeneous populations, where members share similar characteristics, may allow for simpler sampling methods such as simple random sampling, as even a small sample can adequately represent the population. Conversely, heterogeneous populations with diverse characteristics require more structured methods, such as stratified or cluster sampling, to ensure that all subgroups are proportionally represented. For instance, in a study of rural health behaviors across multiple districts, stratifying the population by region, age, or income ensures that variations within the population are captured accurately.

Resource availability, including time, budget, and manpower, is also a critical factor. Probability sampling methods, while statistically robust, often require more time, effort, and financial resources due to the need for randomization and larger sample sizes. When resources are limited, researchers may opt for non-probability techniques such as convenience sampling, which are easier to implement and cost-effective, though they may introduce bias. The researcher must weigh the trade-offs between statistical rigor and practical feasibility when selecting a sampling technique.

The **required level of accuracy and precision** further influences the choice of sampling. Studies demanding high accuracy, such as national surveys or clinical trials, typically employ probability-based methods to reduce sampling error and ensure reliability. In contrast, exploratory or qualitative studies that focus on gaining insights rather than making precise generalizations may rely on purposive or quota sampling. The degree of acceptable error or variability in the results informs how rigorous the sampling process needs to be.

Finally, **population accessibility and variability** play a significant role. Populations that are difficult to access, scattered across wide geographic areas, or hard to identify may necessitate cluster or snowball sampling methods. For example, researchers studying marginalized or hidden communities, such as migrant workers or people with rare health conditions, often rely on snowball sampling, where existing participants refer additional subjects. Understanding these logistical and practical aspects helps in designing a sampling approach that is both effective and efficient. The choice of sampling technique is not arbitrary; it is a systematic decision influenced by multiple factors, including research objectives, population characteristics, resource availability, accuracy requirements, and accessibility. A careful assessment of these factors ensures that the selected sampling method provides a representative sample, reduces bias, and enhances the credibility and reliability of the research findings. Researchers who thoughtfully consider these elements are better equipped to design studies that produce meaningful and valid insights about the population under investigation.

CLASSIFICATION OF SAMPLING TECHNIQUES IN AGRICULTURAL EXTENSION RESEARCH

In agricultural extension research, the selection of an appropriate sampling technique is essential to gather reliable data that reflects the diversity of farmers' practices, perceptions, and challenges. Sampling methods are broadly classified into **Probability Sampling** and **Non-Probability Sampling**. Each type has distinct advantages, limitations, and applications, particularly in studies focusing on rural communities, farm management practices, adoption of technologies, or extension interventions.

A. Probability Sampling

Probability sampling is a method in which every member of the population has a known, non-zero chance of being selected. This type of sampling is widely used in quantitative research because it minimizes bias and allows findings to be generalized to the population. In agricultural extension studies, probability sampling is crucial when the research aims to evaluate adoption patterns, training impacts, or the effectiveness of extension programs across a diverse set of farmers.

Simple Random Sampling (SRS) is one of the most straightforward probability sampling techniques. In SRS, every farmer in the study population has an equal probability of selection, often achieved using random number tables or computer-generated random numbers. This method is particularly suitable for homogeneous populations where farmers share similar characteristics, such as size of landholding or crop type. For instance, if an extension researcher wants to assess the use of organic fertilizers in a district with 2,000 registered farmers, selecting a random sample of 200 farmers ensures that each farmer has an equal chance of being included, which helps in obtaining unbiased insights into the adoption levels.

Systematic Sampling is another commonly used probability method in agricultural research. Here, researchers select every k-th farmer from an ordered list, where the interval k is determined by dividing the population size by the desired sample size. Systematic sampling is easier to implement than SRS and ensures uniform coverage of the population. For example, a researcher conducting a study on farmers' awareness of mobile-based advisory services might select every 5th farmer from a village registration list. While this method is efficient, caution is necessary because if the population list has an underlying pattern, it may introduce bias.

Stratified Sampling is especially useful when the population is heterogeneous, and key subgroups need to be adequately represented. In stratified sampling, the population is divided into homogeneous subgroups (strata) based on characteristics such as crop type, landholding size, or socio-economic status. Samples are then drawn from each stratum proportionally or equally. For instance, in a study evaluating the adoption of precision agriculture technologies, farmers could be stratified by farm size—small, medium, and large—and samples drawn proportionally from each group. This ensures that the perspectives of all categories of farmers are reflected in the results, reducing sampling error and improving the accuracy of conclusions.

Cluster Sampling is useful when the population is widely dispersed, as it allows the researcher to divide the population into clusters (often villages or blocks) and randomly select entire clusters for data collection. This reduces travel costs and logistical challenges in field research, although it may introduce higher sampling error because farmers within the same cluster may be more similar to each other than to those in other clusters. For example, if a researcher wants to assess the need for training on integrated pest management, they could randomly select 10 villages out of 50 in a district and survey all farmers within those villages. This approach saves time and resources while still providing a representative snapshot.

Multistage Sampling combines two or more sampling techniques to improve efficiency and representativeness in complex populations. Often, researchers first select clusters, then stratify within those clusters, and finally randomly select individual farmers for interviews. This method is particularly useful for large-scale extension studies. For instance, in evaluating the impact of a government crop insurance program, a researcher might first select districts (cluster sampling), then villages within those districts (stratified), and finally farmers within villages (simple random). This ensures a well-distributed sample that accurately reflects regional differences and farm characteristics.

B. Non-Probability Sampling

Non-probability sampling does not provide each member of the population with a known chance of being selected. Although it may introduce bias, it is widely used in agricultural extension research for exploratory, qualitative, or rapid studies where in-depth understanding is more important than statistical generalization. Non-probability methods are cost-effective, quicker, and useful for studying specialized populations.

Convenience Sampling involves selecting respondents who are easily accessible or willing to participate. This method is common in preliminary surveys or field-based pilot studies. For example, an extension officer evaluating a farmer training session might survey only participants present at a particular workshop. While convenient and inexpensive, this method does not guarantee representativeness, as only motivated or available farmers are included.

Judgmental or Purposive Sampling is used when researchers select respondents based on their knowledge, experience, or relevance to the study objectives. In agricultural extension research, purposive sampling is often employed to gain insights from expert or progressive farmers who have adopted new technologies early. For instance, to understand barriers to adopting drip irrigation, researchers may purposively select farmers known to have implemented the technology successfully. This method provides detailed and targeted insights, though results may not be generalized to all farmers.

Quota Sampling ensures representation of specific subgroups in the sample according to pre-determined quotas, such as landholding size, gender, or income. Farmers are selected non-randomly within each quota. For example, in a survey assessing women's participation in agricultural extension programs, researchers may ensure that a minimum number of women farmers from each village are included. While quota sampling improves subgroup representation, it does not eliminate selection bias completely.

Snowball Sampling is especially useful for hard-to-reach or hidden populations. Initial respondents are recruited and then asked to refer other farmers within their network. In agricultural extension, this method can be used to study marginalized or small-scale farmers who are not registered with local extension offices. For example, researchers evaluating the adoption of indigenous farming practices among tribal communities might begin with a few known farmers and ask them to identify others who practice similar techniques. This method helps access populations that are otherwise difficult to reach.

STEP-BY-STEP GUIDE TO DETERMINING THE APPROPRIATE SAMPLING TECHNIQUE IN AGRICULTURAL EXTENSION RESEARCH

Determining the appropriate sampling technique is a crucial step in agricultural extension research, as it ensures that the collected data accurately reflects farmers' practices, knowledge, and attitudes. A well-selected sampling method not only enhances the reliability of the findings but also allows extension professionals to make evidence-based recommendations. The process involves several systematic steps that guide researchers in selecting the most suitable approach for their study objectives, population characteristics, and field constraints.

Step 1: Define the Target Population

The first step in selecting a sampling technique is to clearly define the target population. In agricultural extension research, the population typically consists of farmers, farm workers, or households involved in agricultural activities within a defined geographic area. Researchers must establish inclusion and exclusion criteria, such as type of crops grown, farm size, or participation in extension programs. For instance, if a study aims to evaluate the adoption of improved rice cultivation practices, the target population may include only rice farmers in the Cauvery Delta region. A precise definition of the population ensures that the sample accurately represents the group of interest.

Step 2: Clarify the Research Objectives

Next, researchers must consider the primary objectives of the study. Whether the goal is to describe farmers' current practices, assess the impact of a training program, or explore barriers to technology adoption will influence the choice of sampling method. For studies aimed at generalization and statistical inference, probability sampling methods such as stratified or multistage sampling are preferred. In contrast, for exploratory or qualitative studies, non-probability methods like purposive or snowball sampling may be more appropriate. For example, if the study seeks to identify challenges faced by progressive farmers adopting drip irrigation, purposive sampling would allow the researcher to focus on farmers with direct experience, yielding in-depth insights.

Step 3: Assess Population Characteristics

Understanding the nature of the population is essential for determining the sampling technique. Researchers should consider whether the population is homogeneous or heterogeneous, dispersed or concentrated, and whether subgroups exist that require representation. In heterogeneous populations, stratified sampling ensures that all subgroups, such as small, medium, and large-scale farmers, are included proportionally. Similarly, if farmers are geographically dispersed across villages or blocks, cluster or multistage sampling may be more practical. Accurate knowledge of population characteristics allows the researcher to select a method that captures diversity without introducing bias.

Step 4: Consider Resource Availability

Resource constraints, including time, budget, manpower, and accessibility, play a significant role in choosing a sampling technique.

Probability sampling methods generally require more resources due to the need for randomization, detailed lists, and larger sample sizes. When resources are limited, non-probability sampling methods such as convenience or purposive sampling may be more feasible, though they may compromise representativeness. For example, an extension officer with limited field staff might survey only accessible farmers who participate in local training programs, using convenience sampling to gather preliminary data efficiently.

Step 5: Determine the Desired Level of Accuracy

The level of precision and reliability required for the study also influences the sampling choice. Studies requiring high statistical accuracy, such as evaluating the effectiveness of government subsidy schemes, should employ probability sampling to reduce sampling error. Conversely, exploratory studies aiming to identify trends, perceptions, or challenges can rely on non-probability sampling, where representativeness is less critical. For instance, a qualitative study on farmers' attitudes toward climate-resilient crops may not require large samples, but it should include diverse participants to capture varying perspectives.

Step 6: Select the Sampling Technique

Based on the population characteristics, research objectives, resource availability, and accuracy requirements, researchers can now select the most appropriate sampling method. For example, a large-scale survey on the adoption of mobile-based extension advisory services across multiple districts might use multistage sampling, selecting districts, villages, and then farmers randomly within villages. On the other hand, a case study exploring traditional pest management practices among tribal farmers may use purposive or snowball sampling to identify knowledgeable respondents.

Step 7: Determine the Sample Size

After selecting the sampling technique, researchers must determine the sample size required to ensure reliable and valid results. Statistical formulas, pilot studies, or standard sampling guidelines can be used to calculate the minimum number of farmers needed. The sample size depends on factors such as population size, desired confidence level, margin of error, and variability in the population. In agricultural extension research, larger sample sizes are often necessary in heterogeneous populations to capture variability in practices and adoption levels.

Step 8: Implement and Monitor the Sampling Process

Finally, the sampling plan must be implemented carefully to minimize errors and ensure adherence to the chosen methodology. Field researchers should follow the protocol for selecting respondents, document any deviations, and monitor the process for consistency. In agricultural extension studies, maintaining accurate records of villages, households, and selected farmers is critical to avoid duplication and ensure that all relevant subgroups are represented. Continuous monitoring also allows for adjustments in the field if unexpected challenges arise, such as inaccessible areas or non-response from selected farmers. Determining the appropriate sampling technique in agricultural extension research is a systematic and multi-step process. It begins with defining the population and clarifying research objectives, followed by assessing population characteristics, resources, and desired accuracy. Careful selection of the sampling method, along with calculation of sample size and strict implementation, ensures that data collected from farmers is representative, reliable, and useful for policy-making, program evaluation, and extension planning. By following these steps, agricultural researchers and extension professionals can design studies that effectively capture the realities of rural farming communities and provide evidence-based insights to improve agricultural interventions.

Step-by-Step Process to Determine Sampling Technique

Define Target Population
↓
Clarify Research Objectives
↓
Assess Population Characteristics
↓
Consider Resources (Time, Budget, Staff)
↓
Determine Required Accuracy / Precision
↓
Select Appropriate Sampling Technique
↓
Determine Sample Size
↓
Implement Sampling and Monitor Fieldwork
↓
Collect Data and Ensure Representativeness

CONCLUSION

The determination of sampling techniques is a critical component of agricultural extension research. Proper sampling ensures that collected data is representative, reliable, and actionable, which is essential for informing extension strategies, policy interventions, and program evaluations. Probability sampling methods are ideal for studies requiring statistical generalization, while non-probability methods are useful for qualitative or exploratory research. By carefully defining the population, considering research objectives, evaluating resources, and systematically selecting a sampling approach, agricultural researchers and extension professionals can generate accurate, credible insights that improve decision-making and enhance the effectiveness of extension services. Effective sampling ultimately bridges the gap between research and practical impact in rural farming communities.

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SPRAY-INDUCED GENE SILENCING - THE SMART SPRAY CHANGING THE FUTURE OF CROP PROTECTION

Abstract

With global food security increasingly threatened by climate change and escalating pest issues, the agricultural sector's dependence on chemical pesticides is proving unsustainable due to their negative environmental impact. This highlights the necessity for innovative RNA interference (RNAi) based strategies that offer safer, more precise, and environmentally friendly crop protection. RNAi is a biological mechanism in which non-coding double-stranded RNA is used to specifically silence crucial pest genes in infected hosts, thereby diminishing the pests' capacity to feed, proliferate, and survive. Although spray-induced gene silencing (SIGS) through RNAi might seem complex, it fundamentally involves using non-coding RNA molecules to obstruct harmful pests and diseases without altering the plant itself.

Keywords: RNA interference, non-coding double-stranded RNA, Spray-induced gene silencing

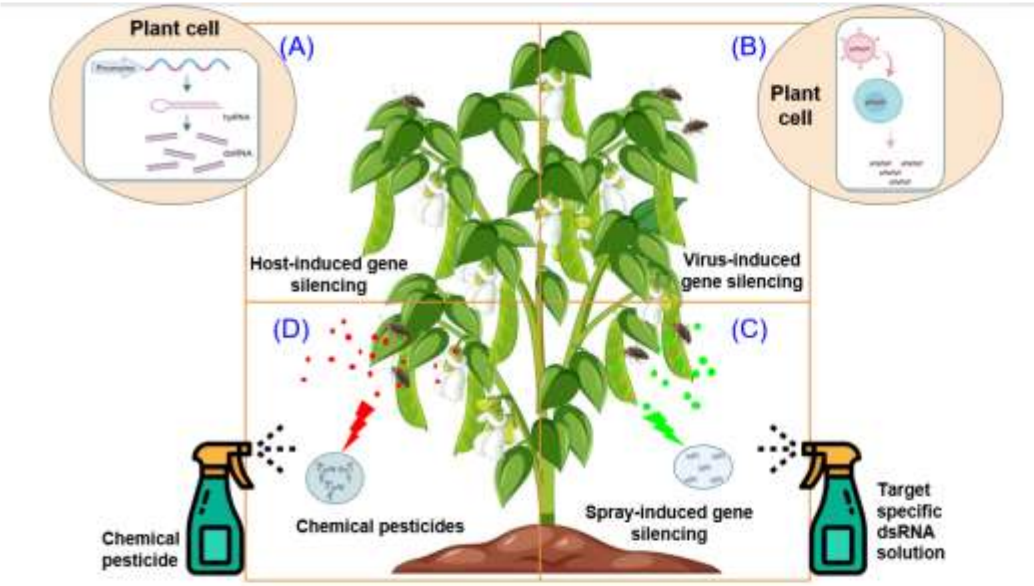

Figure 1: Pest control strategies. (A) Host-induced gene silencing: dsRNA produced in the host plant is taken up by the pathogen or pest, where it activates RNAi and silences the target gene. (B) Virus-induced gene silencing: viral vector delivers dsRNA into the plant, triggering RNAi that specifically degrades the target gene's mRNA when taken up by a pathogen or pest. (C) Spray-induced gene silencing: dsRNA or siRNA, which is applied externally, is absorbed by the pest and triggers RNAi to silence the target gene. (D) Chemical pesticides.

What makes spray-induced gene silencing (SIGS) a compelling option?

Traditional RNAi methods, such as host-induced gene silencing (HIGS) and virus-induced gene silencing (VIGS), are not only time-consuming and expensive but also involve genetic modification, which can lead to consumer concerns and regulatory challenges. SIGS, on the other hand, offers a more attractive solution because it eliminates the need to alter the genome. This method is particularly advantageous for crops that are challenging to modify using transgenic and gene-editing techniques.

Introduction

SIGS represents an innovative, eco-friendly alternative to conventional chemical pesticides and to transgenic RNAi systems, in which plants are genetically engineered to produce their own RNAi molecules. Therefore, SIGS is increasingly recognised as a promising biopesticide strategy. The underlying feasibility of SIGS relies on the principle of environmental RNAi, in which pests and pathogens can directly absorb externally applied double-stranded RNA (dsRNA) or small interfering RNA (siRNA) molecules from their environment. When these RNA molecules are delivered to plant surfaces via foliar spray, they function similarly to conventional crop protection inputs but with far greater biological precision. Because SIGS does not rely on stable genetic transformation of host plants, it can be effectively deployed in both monocots and dicots to suppress a wide range of pathogens. As SIGS is not involved in plant transformation, it is effectively used in monocots and dicots for pathogen suppression. In contrast, insects that chew can easily take up the sprayed dsRNAs, which are known to invade the cuticle of some insect species. In insect pests, particularly chewing insects, the uptake of sprayed dsRNA is facilitated through ingestion during feeding or penetration through the cuticle in species with permeable integuments. Once internalized, the dsRNA triggers the RNAi machinery, leading to the silencing of essential genes and ultimately reducing pest survival, virulence, or infection ability. Thus, SIGS integrates biological specificity with environmental compatibility, offering a highly targeted, sustainable and adaptable approach to crop protection.

Mechanism

SIGS functions as an exogenously applied RNAi-based strategy that mediates post-transcriptional gene silencing in target pests and pathogens. In this approach, long double-stranded RNA (dsRNA) or single-stranded RNA (ssRNA) molecules are synthesized in vitro and delivered to plant surfaces via foliar spray. Once applied, these RNA molecules are taken up by the invading pest or pathogen during feeding or surface contact, triggering RNA interference (RNAi) without causing heritable genetic modifications in the plant. The dsRNA is digested by Dicer, an RNase III ATP-dependent nuclease, which initiates processing and produces uniformly sized small RNAs called small interfering RNAs (siRNAs). These are uncoiled into single strands and further incorporated into an RNA-induced gene silencing complex (RISC). The Argonaute protein, a central component of the RISC, binds to the specific target mRNA through sequence complementarity, leading to mRNA cleavage or translation inhibition. By targeting downregulation of essential or virulence-associated genes, SIGS effectively impairs the growth, survival, or pathogenicity of the pest or pathogen without introducing heritable modifications into the host plant.

Advantages

- **Non-Transgenic and Publicly Acceptable**

Since no stable genetic transformation occurs, the treated plants remain non-transgenic, simplifying regulatory approval and enhancing consumer acceptance.

❖ **Environmentally Benign Mode of Action**

Exogenously applied dsRNA degrades rapidly in the environment and exhibits high sequence specificity, targeting only the intended pest or pathogen genes. This minimizes the impact on non-target and beneficial organisms, making SIGS an eco-friendly alternative to conventional pesticides.

❖ **Independence from Plant Transformation**

Because SIGS does not require genetic modification of host plants, it is applicable across a wide range of crop species, including recalcitrant or difficult-to-transform species. This expands its utility to both monocots and dicots.

❖ **Rapid Deployment and Immediate Effect**

Unlike transgenic approaches such as HIGS, SIGS can be deployed rapidly since the dsRNA molecules can be produced in vitro and applied directly to plant surfaces. This facilitates timely protection against emerging pest and pathogen outbreaks.

❖ **Lower Research and Development Costs**

SIGS avoids the time-consuming and resource-intensive processes required for transformation, regeneration, and biosafety evaluation in gene-edited crops. Therefore, it generally involves lower development costs compared to host-induced or virus-induced gene silencing methods.

❖ **Transient and Non-Heritable Silencing**

The gene silencing induced by SIGS is temporary because the applied RNA molecules are eventually degraded and do not integrate into the plant genome. This reduces long-term ecological concerns associated with heritable genetic modifications.

❖ **Reduced Chemical Pesticide Usage**

SIGS offers a biologically targeted pest management approach, contributing significantly to reducing reliance on synthetic pesticides and supporting sustainable agriculture.

❖ **High Safety for Humans and Animals**

RNA molecules are natural and readily degraded by nucleases in the human digestive system. Thus, dsRNA-based treatments pose minimal risk to human and animal health.

❖ **High flexibility and Target-specific Redesigning**

If new pathogen strains or insect races emerge, the dsRNA sequence can be rapidly redesigned to match the altered target gene, making SIGS adaptable for dynamic pest populations.

Limitations

❖ **Limited Stability of RNA Molecules**

Both single-stranded and double-stranded RNAs are naturally unstable and prone to degradation by environmental factors such as UV radiation, high temperatures, and RNases. This limits how long dsRNA remains on plant surfaces.

❖ **Short Environmental Persistence**

While the rapid degradation of dsRNA minimizes ecological risks, it also reduces the duration of protection, necessitating repeated applications to maintain effective gene silencing in the target organism.

❖ **Public Misconceptions and Awareness Challenges**

A major constraint is public misunderstanding of RNA-based technologies. Although SIGS is a non-GM approach, awareness campaigns are needed to ensure stakeholders and consumers clearly understand that it does not alter the plant's genetic makeup.

Applications

SIGS has been effectively used to control various pests and pathogens, and its efficiency increases when dsRNA is delivered through nanocarriers. Chitosan, a biodegradable and positively charged polymer, forms stable complexes with dsRNA, protecting it from degradation and improving uptake by target organisms. This chitosan-based delivery offers a more specific, safe, and eco-friendly alternative to conventional pesticides.

Conclusion

SIGS is a promising non-GMO, eco-safe tool, but deeper biological understanding and collaboration with material scientists are needed to improve RNA delivery and stability. Extensive field studies are required to confirm the effectiveness of SIGS and integrate it into precision farming for sustainable crop protection.

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BARRIERS TO SUSTAINABLE SOURCING IN THE APPAREL AND FASHION LUXURY INDUSTRY

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ABSTRACT

Sustainable sourcing in the apparel and fashion luxury industry is a vital strategy that promotes environmental stewardship, ethical labor practices, and social responsibility. This article examines sustainable sourcing, focusing on eco-friendly materials such as natural fibers and dyes, and critically analyzes the significant barriers the industry faces in sourcing these materials sustainably. These barriers include supply limitations, cost implications, quality inconsistencies, lack of standards, environmental-social trade-offs, technological challenges, and supply chain transparency. Addressing these challenges is crucial to advancing responsible luxury fashion production.

INTRODUCTION

Sustainable sourcing refers to acquiring raw materials and products through channels that prioritize ethical production, environmental protection, and social equity. It involves a conscious effort to reduce negative ecological impacts by adopting materials and processes that minimize pollution, conserve resources, and improve labor conditions across the supply chain. In the luxury apparel sector, sustainable sourcing has evolved beyond a marketing trend into an operational imperative, driven by heightened consumer awareness, regulatory requirements, and a corporate commitment to responsibility.

Central to sustainable sourcing are the adoption and promotion of natural fibers—including organic cotton, wool, silk, hemp, flax, and linen—which are cultivated and processed under stringent eco-friendly standards to reduce chemical use, water consumption, and social exploitation. Similarly, natural dyes sourced from plants, minerals, and insects offer a non-toxic, biodegradable alternative to synthetic dyes, supporting biodiversity and preserving traditional craftsmanship. Together, these materials embody the luxury sector's aims for authenticity and sustainability, yet their procurement introduces unique challenges that require thorough examination.

Key Barriers to Sustainable Sourcing

- Scarcity and Supply Limitations: The dependency of natural fibers and dyes on agricultural conditions results in limited availability and seasonal variability. Factors such as climate change, competition for arable land, and fluctuations in crop yields constrain steady supply. Notably, the volume of plant or animal material required for natural dyes is substantially higher than for synthetic options, limiting large-scale feasibility.

- **Cost Challenges**
  - Higher cultivation and processing costs arise from labor-intensive practices, certification requirements, and limited economies of scale. These factors make natural fibers and dyes more expensive than their synthetic counterparts, leading to price pressures in luxury production.

- Quality and Consistency Issues
  - Variability in color shade, dye fastness, and fiber quality pose risks to design uniformity and product reliability. Natural dyes' sensitivity to environmental and processing parameters can result in inconsistent outcomes, challenging brand quality standards.

❖ Lack of Standardization and Certification

➢ The fashion industry's current lack of universally accepted certification systems for natural fibers and dyes undermines traceability and consumer trust. Inconsistent standards hinder verification of sustainability claims.

❖ Environmental and Social Trade-Offs

➢ Sourcing natural materials demands considerable land and water resources and, if unregulated, risks environmental degradation. Additionally, ensuring fair labor practices among farmers and dyers remains complex and essential.

❖ Processing and Technological Barriers

➢ The artisanal and less industrialized nature of natural dyeing and fiber processing limits scalability and efficiency. Investment in eco-friendly manufacturing technologies is still inadequate.

❖ Supply Chain Transparency and Traceability

➢ Fragmented global supply chains complicate monitoring and verification of sustainable practices. Emerging technologies like blockchain are not yet widely integrated to ensure accountability.

CONCLUSION

Sourcing natural fibers and dyes sustainably is pivotal for the apparel and luxury fashion industry's transition to responsible production. However, overcoming challenges such as supply scarcity, cost increases, quality variability,

lacking standards, environmental impact trade-offs, technological gaps, and transparency issues is essential. Collaborative efforts among industry stakeholders, advancements in technology, and robust governance frameworks can enable luxury brands to meet their sustainability commitments and align with evolving consumer expectations.

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PHOSPHORUS IN AGRICULTURE:

DYNAMICS AND FUTURE HORIZONS

Abstract

Phosphorus (P) is the second most critical macronutrient for crop production, serving as the biological "energy currency" through its role in ATP synthesis and genetic transfer. Despite its physiological necessity, Phosphorus management remains a complex challenge in agriculture due to its low solubility and high reactivity in soil. This article reviews the fundamental chemistry of Phosphorus, its behavior in different soil pH environments, and the mechanisms of fixation that limit its bioavailability to less than 20% of applied inputs. We examine the distinct deficiency symptoms in crops and current mitigation strategies. Furthermore, the article highlights the paradigm shift in Indian agriculture towards high-efficiency solutions, including the adoption of Nano-DAP, biological solubilization through microbial consortia, and the move towards a circular economy via Struvite recovery. These emerging technologies promise to enhance Nutrient Use Efficiency (NUE) and ensure sustainable production in the face of dwindling global rock phosphate reserves.

Keywords: Phosphorus Fixation, ATP, Nano-DAP, Soil Fertility, Nutrient Use Efficiency (NUE), Sustainable Agriculture, Struvite.

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1. Introduction: General Scientific Profile & Atomic Properties

Phosphorus is a non-metal of the Nitrogen family, essential for all life forms. Its behavior in the soil-plant system is deeply rooted in its fundamental atomic properties.

Agricultural Significance of Atomic Structure:

- **Symbol:** P
- **Atomic Number:** 15
- **Atomic Mass:** 30.97 u
- **Electron Configuration:** [Ne] $3s^2 3p^3$
- **Group:** 15 (Pnictogens)
- **Period:** 3
- **Block:** p-block
- **Valence:** Commonly exhibits oxidation states of -3, +3, and +5.

While Phosphorus shares Group 15 with Nitrogen, it does not have a significant gaseous phase in the atmosphere, making it a sedimentary cycle. Chemically, P is highly reactive due to its valence electrons. In agricultural soils, it almost exclusively exists in the oxidized +5 state as the orthophosphate oxyanion (PO_4^{3-}). This negative charge drives it to react rapidly with positively charged soil cations (Calcium, Iron, Aluminum), leading to the phenomenon of "fixation," which renders it unavailable to plants.

Stable Phosphorus-31 (^{31}P) is the only naturally occurring isotope, the radioactive isotope Phosphorus-32 (^{32}P) is frequently used in agricultural research as a tracer to map root uptake patterns and fertilizer efficiency.

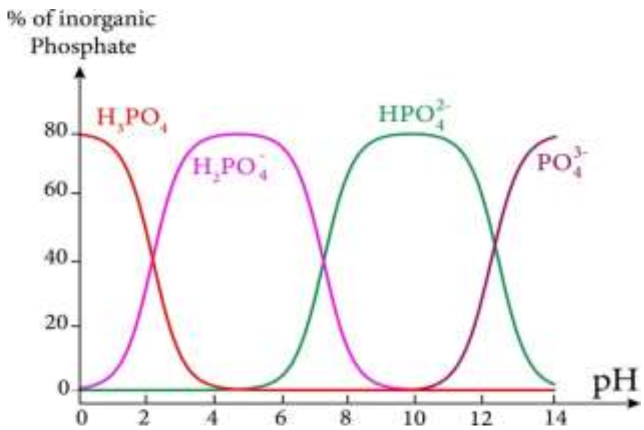
2. Physiological Role in Plants

Phosphorus is often referred to as the "energizer" of the plant world due to its central role in energy storage and transfer.

- **Energy Transfer:** It is the structural backbone of **Adenosine Triphosphate (ATP)** and **ADP**. During photosynthesis and respiration, energy is stored in the high-energy phosphate bonds of ATP, driving nearly all metabolic processes.
- **Genetic Integrity:** P is a constituent of the sugar-phosphate backbone of **DNA** and **RNA**, making it indispensable for cell division, genetic reproduction, and protein synthesis.
- **Cell Membrane Structure:** It forms **phospholipids**, which create the bilayer of cell membranes, regulating the entry and exit of solutes.
- **Crop Development:**
    - ✓ **Rooting:** Promotes vigorous early root formation (lateral and fibrous roots).
    - ✓ **Maturity:** Accelerates crop maturity and promotes uniform flowering.
    - ✓ **Legume Nodulation:** Essential for the formation of nodules in leguminous crops for Nitrogen fixation.
    - ✓ **Stalk Strength:** It contributes to structural strength, preventing lodging in cereal crops.

3. Soil Dynamics: Forms, Pools, and Fixation

Plants cannot absorb elemental phosphorus; they must take it up as inorganic orthophosphate ions dissolved in the soil solution. The specific form absorbed is highly dependent on soil pH.



Plant Uptake Forms

- **Dihydrogen Phosphate ($H^2PO_4^-$)**
- ✓ Dominant in **acidic soils** (low pH).
- ✓ Most readily absorbed form by plants.
- **Monohydrogen Phosphate (HPO_4^{2-})**
- ✓ Dominant in **alkaline soils** (high pH).
- ✓ Absorbed less rapidly than the dihydrogen form.

Phosphorus Pools in Soil

Soil phosphorus exists in three distinct "pools" based on availability.

- **Solution Pool (Immediate Availability):**
  - ✓ Contains very small amounts of P (approx. 0.001 to 1 mg/L) dissolved in soil water.
  - ✓ This is the only pool plants can draw from directly. It must be replenished continuously.
- **Labile (Active) Pool:**
  - ✓ Solid P held on soil surfaces that can rapidly desorb to replenish the solution pool.
- **Non-Labile (Fixed/Stable) Pool:**
  - ✓ Contains the vast majority of soil P (both organic and inorganic).
  - ✓ This P is chemically locked in insoluble compounds and is released extremely slowly (over years).

Phosphorus Fixation and Mobility

A major challenge in agriculture is that P is highly **immobile** and reactive. Unlike Nitrogen, which leaches easily, P gets "fixed" (precipitated) into insoluble forms.

Fixation Mechanisms

- **In Acidic Soils (pH < 6.0):** P reacts with **Iron (Fe^{3+})** and **Aluminum (Al^{3+})** to form insoluble iron and aluminum phosphates (e.g., strengite, variscite).
- **In Alkaline Soils (pH > 7.5):** P reacts with **Calcium (Ca^{2+})** to form insoluble calcium phosphates (e.g., apatite).
- **Maximum Availability:** Occurs in the neutral pH range of **6.0 to 7.0**.

Mobility

- **In Soil:** P moves primarily by **diffusion** (from high to low concentration). This movement is extremely slow (often < 1 cm).
- **In Plants:** P is **mobile**. When deficiency hits, the plant translocates P from older tissue to new growing points.

4. Deficiency Guide: Symptoms & Diagnosis

Because Phosphorus is **mobile** within the plant, it is translocated from older tissues to actively growing points when supply runs low. Therefore, symptoms appear on **older leaves** first.

- **Visual Symptoms:**
  Purple Coloration: The most distinct symptom. Accumulation of sugars (due to energy transport failure) leads to the synthesis of **anthocyanin pigments**, turning leaves dark green to reddish-purple.
  Stunted Growth: Plants appear dwarfed with spindly stems.
  Poor Rooting: Reduced root mass, limiting water and nutrient uptake.
  Physiological Impact: Delayed maturity, poor seed setting, and reduced disease resistance.

5. Management Strategies (Current Mitigation)

Traditional management focuses on overcoming fixation and placing nutrients near the roots.

- **Band Placement:** Since P is immobile, applying fertilizer in a band 5 cm below and to the side of the seed (starter fertilizer) makes it accessible to roots without mixing it into the entire soil volume (reducing fixation).
- **Soil Amendments:**

✓ **Liming:** Adding lime to acid soils raises pH, precipitating Al and Fe, thus releasing fixed P.

✓ **Organic Matter:** Manure and compost release organic acids that chelate (bind) Fe and Al, preventing them from locking up P.

- **Bio-fertilizers:** Use of Phosphate Solubilizing Bacteria (PSB) like *Pseudomonas striata* and *Bacillus polymyxa*, or mycorrhizal fungi (VAM), which secrete organic acids to dissolve insoluble phosphates.

8. Future Aspects of Phosphorus Management

As India imports nearly **90%** of its phosphate requirements (primarily as rock phosphate and phosphoric acid), the future of P management is driven by three goals: **Import Reduction, Efficiency Improvement, and Environmental Sustainability**.

- **Nano-Technology (Nano-DAP):**

✓ A major shift from bulk to foliar application.

✓ **High Efficiency:** Nanoparticles (<100 nm) bypass soil fixation, increasing Nutrient Use Efficiency (NUE) from 15-20\% to **50-60%**.

✓ **Logistics:** One **500 ml** bottle effectively replaces a **50 kg** bag of conventional DAP.

- **Circular Economy (P-Recycling):**

✓ **Struvite Recovery:** Extracting Phosphorus from urban wastewater as slow-release, eco-friendly fertilizer.

✓ **PROM (Phosphate Rich Organic Manure):** Utilizing low-grade indigenous rock phosphate by co-composting it with organic waste to solubilize P.

- **Precision Management:**

✓ **GIS Mapping:** Moving from blanket applications to **Variable Rate Application (VRA)** based on digital soil maps.

✓ **Micro-dosing:** Soil Health Cards now emphasizing timing and placement (micro-dosing) rather than just basal application.

- **Biological Interventions:**

✓ **Bio-Consortia:** Using advanced inoculants combining PSB (*Bacillus/Pseudomonas*) and Mycorrhiza (VAM).

✓ **Genetic Engineering:** Breeding **P-efficient genotypes** with steeper root angles and higher organic acid exudation to "mine" fixed soil P.

- **Policy Reforms:**

✓ **Fortification:** Subsidy shifts favoring P-fertilizers fortified with **Zinc** and **Boron**.

✓ **Site-Specific Nutrient Management (SSNM):** transitioning from state-level to localized nutrient protocols.

- **Band Placement:** Applying fertilizer in a band (5 cm below and to the side of the seed) concentrates the nutrient, reducing soil contact and fixation while ensuring easy access for young roots.

- **pH Management:**

✓ **Liming:** Adding lime to acidic soils precipitates Al and Fe, releasing fixed P.

- ✓ **Sulfur/Gypsum:** Used in alkaline soils to lower pH locally.

- **Organic Amendments:** Manure and compost release organic acids during decomposition. These acids form complexes (chelates) with Iron and Aluminum, preventing them from locking up Phosphorus.

7. Conclusion

Phosphorus stands as a paradox in agricultural science: it is physiologically indispensable yet geochemically elusive. The management of Phosphorus is no longer a simple equation of "inputs versus yield." With global rock phosphate reserves being finite and the environmental risks of eutrophication rising, modern agriculture faces a critical turning point. The future lies in an **Integrated Phosphorus Management (IPM)** strategy that combines nanotechnology, biological synergy, and precision agriculture to unlock the vast reserves of "Legacy Phosphorus" in our soils. Ultimately, sustainable Phosphorus management is about securing the bio-energetic foundation of global food security.

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A Farmer-Level Success in Mandya, Karnataka: Eco-friendly Management of Root-Knot Nematode in Paddy through Biofor PF-2 enriched FYM

Introduction

Rice (*Oryza sativa* L.) is the most important staple food crop in Karnataka, grown widely under irrigated and semi-dry conditions. In recent years, the rice root-knot nematode, *Meloidogyne graminicola*, has emerged as a major hidden threat, particularly in the Cauvery command areas. Unlike foliar pests, nematode infestations often go unnoticed until yield losses become severe. *M. graminicola* is known for its ability to cause characteristic hook-shaped galls on roots, restrict nutrient uptake, and stunt plant growth.

The pyriform-shaped females lay eggs within the root cortex, where juveniles undergo their first molt inside the eggs, developing into pre-parasitic second-stage juveniles. These second-stage juveniles are initially non-parasitic but become parasitic once they invade the root elongation zone. Throughout the year, soil population levels fluctuate, influenced by factors such as soil structure, temperature, pH, moisture, and the plant's growth stage, all of which affect the nematode's survival and infection capability.

The newly parasitic second-stage juveniles migrate intercellularly within the rice root cortex towards the root tip. There, they penetrate the vascular cylinder and establish specialized feeding sites in the stele near the root meristem by inducing the formation of five to eight giant cells. Once established, the nematode becomes sedentary and feeds on these giant cells. After undergoing three more molts, it reaches adulthood—females adopting a pear-shaped form, while males appear threadlike.

Unlike other *Meloidogyne* species, where eggs are laid in egg masses protruding into the soil, *M. graminicola* lays eggs protected inside the root cortex. This offers protection from predators, pathogens, and host immune responses. This adaptation also allows the nematode to survive flooded conditions common in rice cultivation. The next generation of nematodes develops inside these internal egg masses, continuing to form additional feeding sites within the root.

The increasing incidence of nematodes in farmers' fields has highlighted the urgent need for sustainable management strategies that enhance soil health while reducing chemical dependency. Biological control using beneficial microbes enriched in organic substrates has shown promise as an eco-friendly option. This success story highlights an effective field intervention demonstrating the potential of enriched organic amendments to manage *M. graminicola* in farmer fields.

Farmer Details

- **Farmer Name:** Shri. Chandra Mohan
- **Location:** Vaddaragudi, K.R. Pete Taluk, Mandya District, Karnataka
- **Problem Identified:** Severe infestation of *Meloidogyne graminicola* in paddy

Shri. Chandra Mohan approached the nematologists' team for solutions after observing unusual stunting and poor growth in his rice field during the early tillering stage. During field inspection, the following symptoms were recorded:

Above-Ground Symptoms

- Stunted seedlings with uneven growth
- Poor tillering and weak secondary shoots
- Yellowing of foliage, mimicking nutrient deficiency
- Reduced vigor and delayed crop establishment

Below-Ground Symptoms

Upon uprooting and washing the roots:

- Extensive galling characteristic of *Meloidogyne* infection
- Poor root branching
- Reduced root biomass

Initial soil analysis indicated a nematode population of 475 juveniles per 200 cc soil, reflecting a high level of infestation. To provide an eco-friendly solution, the farmer was advised to adopt biological management using FYM enriched with Biofor PF-2, a *Pseudomonas fluorescens* formulation known for its antagonistic activity against plant-parasitic nematodes. Application rate: FYM enriched with Biofor PF-2 @ 20 g/m²

Method of Application

- Preparation of enriched FYM: FYM was thoroughly mixed with Biofor PF-2 @ 20 g/m²**.**
- Application timing: Applied as basal dose before transplanting.
- Incorporation: Spread uniformly and mixed into the top 10–12 cm of soil.

Mode of action: Improvement of soil organic matter, enhancement of antagonistic microbial activity, and suppression of nematode populations.

Outcome and Impact

The intervention resulted in:

- Significant reduction in nematode population:
  - *Before treatment:* 475/200 cc soil
  - *After treatment:* 123/200 cc soil

Before treatment After treatment Galled roots

- Improved plant growth, enhanced tillering and uniform growth, Greener foliage indicating improved nutrient uptake, Strong, well-branched root systems, Faster crop recovery compared to the untreated area
- **Yield enhancement:** The farmer recorded a 35% increase in grain yield after adopting the enriched FYM treatment. This improvement is significant for a smallholder farmer in a region where even 10–15% yield enhancement is economically meaningful.
- **Economic benefit**: The cost–benefit assessment showed a Benefit–Cost Ratio (B:C) of 1:2.9**,** clearly demonstrating the profitability of the intervention. Low input cost (locally available FYM + Biofor PF-2), High economic return through increased yield.
- **Soil health improvement**: Beyond nematode management, the practice contributed to increased microbial activity, higher organic carbon content, improved soil texture and water-holding capacity. These benefits support long-term soil sustainability and resilience of the cropping system.

Conclusion

The success of Biofor PF-2 enriched FYM in Shri. Chandra Mohan’s field demonstrates the practical feasibility and effectiveness of biological management against *Meloidogyne graminicola* in rice-growing regions of Karnataka. This eco-friendly approach not only suppresses nematode populations but also enhances soil health and productivity, offering a sustainable alternative to chemical nematicides.

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BEHIND THE PRICE TAG OF FOOD

Introduction

Each grain of rice, every thing grown on our plate has a secret behind it. While consumers in the market pay a high price, the farmers who grow it sometimes receive very little. The hard reality is that between the farmer and the consumer there exist many middlemen who get a large cut of the profit.

Have you ever asked yourself why the onions that a farmer sells at ₹2 per kilo in Nashik are retailed for ₹30 (preferably) in Delhi? Or how the farmer sells tomatoes at ₹5 a kg to middlemen, who in turn sell it for ₹50 in the city market? It's not there in the quality of the produce, but rather in the countless layers of traders, middlemen and retailers that stand between our soil and the supermarket shelf.

Farmers,the bedrock of our nation, in popular rhetoric are now in an ironic situation: They feed millions yet they cannot feed their own families. This article tells their story, not only story but reality.

Farmers cost

In order to see the unequal status, we shall enter the mind of a farmer. Consider the example of Ramesh, a marginal farmer in Maharashtra who grows tomatoes on his land that is two acres. He starts his quest several months before harvest: He purchases the seeds of a private company at high prices. He invest money into fertilizers, pesticides, and irrigation. Paying the labor, electricity to pump the water and transportation to the mandi increase his costs. Ramesh has spent almost 25,000 before his crop is ready. And when he comes to the market yard the truth strikes him a hard blow. He is given 4-5 per kilo only to repay a fraction of the input costs. This is not the story only of Ramesh. Millions of farmers across India are spending months cultivating crops and in the process, taking local loans at high-interest rates. However, when the selling day arrives, they have to accept the price offered by middlemen. The price of agriculture is very expensive, yet the payoff is exceedingly low.

The Role of Middlemen's

The role of the middlemen In many Indian agricultural markets farmers cannot directly sell their produce to the customers. Instead, they have to go through the myriad of commission agents and traders that dominate the local mandis. Often, these middlemen also dictate the terms of sale, leaving little room for negotiation for the farmers.

Typically, the trader is much preferred with the manner the process works out. Farmers accept any price that is presented to them since they are already facing pressure to clear their produce as they do not have any storage facility. Prices at which the middlemen purchase crops are so low that they are at times even lower than the cost of producing the crops. After that, they market the same food to food processing firms, wholesalers and retailers at a price that is much higher. When these vegetables, grains or fruits finally reach the kitchen of the consumer, the price has doubled or even tripled. The irony in this situation is that when people are lamenting of the high food prices within urban setting, the farmer who cultivated the food has practically no left. Rather than the hardworking farmers, the existing system is benefiting those who have not planted even a single seed or worked in fields.

The Price Difference: Farmer vs Consumer

The difference between farmer income and consumer prices is so huge. It has been found that Indian farmers get 20 to 25 percent of the retail price in their products. Farmers receive? 8 per kilograms of potatoes and consumers pay? 30 per kilograms of potatoes. The farmers gain? 15 per kilogram of rice, and the consumers pay? 50. Consumers will pay? 60 a liter of milk and farmers will receive only? 20. This disparity in prices reflects institutional inequality and exceeds quantitative indicators. Consumers are complaining of buying at high prices, farmers are complaining of low income. Middlemen gain and both parties lose. This is even worse when there are bumper harvests. When there is high production, farmers are willing to earn more. Rather, it is the excess that middlemen capitalize on, thereby leading to a decrease in the prices. Some vegetables such as tomatoes and onions can be found on the road side not because they are spoilt, but because farmers are cheaply disposed to dump them rather than they are paid embarrassingly low prices. This creates a very uncomfortable question, why does the food farmer make the least in the food chain?

The Emotional Cost

This injustice does not only affect the pocket of a farmer negatively, but also affects his heart. Even though they get up before sunrise, work in bad weather, and never have a break, farmers are poor. The most innocent individuals are not able to access basic health care. Most of the agricultural kids will drop out of school since they are unable to meet the fees. Families survive on a day to day basis and they continually attempt to settle their debts and get to the next crop season. The most terrible of all is the crisis of mental health. According to the National Crime Records Bureau, thousands of farmers in this country commit suicide annually due to debt, crop failures and exploitation in the market. These are not mere numbers, these are stories of fathers, mothers and young men who lacked any hope of leading a life full of struggle. Their deaths themselves and the following silence cause the tragedy. And although the farmer suicides get publicity a few days, the issues behind them are seldom resolved. The process repeats itself, decade after decade, generation upon generation.

The Way Forward

This crisis needs both systemic and collective action to be solved. Here are some pathways:

Farm Producer Organizations (FPOs):

- The collectivism enables farmers to share resources, bargaining prices as well as direct selling to large consumers like supermarkets or exporters.
- This minimizes the application of middle men.

Direct-to-Consumer Markets:

- The void can be filled in with farmers markets, farm to home applications and e-commerce websites. The examples of Ninjacart and BigHatta show that technology can be used to match farmers with consumers.

Government Support

- Increase min floor price (MSP) system. Store cold so that there can be no distress sales.
- Promote open e-trading.

Infrastructure & Technology

- Improved roads, warehouses, and rural transportation will enable reduction in the wastes and also enable farmers to be in better control
- . Through mobile applications which notify farmers about the prevailing prices in the market, the farmers are able to know the right location to sell their farm produce.

Consumer Responsibility

- The presence of the role of urban consumers is also present. They can achieve it by buying their product in the local farmers market, buying farm cooperatives and knowing more about the plight their food undergoes so as to make sure that the farmers hit a better deal.

Conclusion

When we next see the price of food in the marketplace it is worth asking ourselves what percentage of it ends up in the hands which bring it into the world. A life of sacrifice and hard work lies behind each grain of rice that a farmer has worked on, and then there is a month of effort and denial that is the background of each vegetable. The farmers are known to get up before the sun rises, deal with unpredictable weather and to fight rising expenses. But when their yield at last gets to our tables, they are only paid a little of the money we spend. The real price of food will always remain behind that price tag until the farmers are given their fair share. The dignity of a farmer has nothing to do with what we say to him and celebrate special days. It derives out of equitable and sustainable income. We should minimize the misuse of middlemen, have better direct access mechanisms to the market as well as policies that acknowledge the efforts of the farmer. We can increase the bargaining power of farmers by supporting their organizations such as farmer-producer organizations, online marketplaces, and cooperative models. Those who really respect farmers do not use any slogans but rather make sure that those who feed the nation never have to go to bed hungry themselves.

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BIO-FIBER EXTRACTION FROM ALGAE AND WATER PLANTS: A NEW ERA FOR SUSTAINABLE FASHION

Abstract:

The global fashion industry is urgently seeking sustainable and circular alternatives to mitigate its heavy environmental impact, which is primarily driven by the resource-intensive nature of traditional natural fibers and the microplastic pollution associated with synthetic textiles. This article highlights the innovative and regenerative potential of bio-fiber extraction from algae and invasive water plants as a critical paradigm shift. Algae-based fibers, derived from rapidly growing, absorbing, and fully biodegradable resources, require no arable land or freshwater. Their processing yields cellulose-rich fibers or biopolymers like alginate, which can be spun into soft, durable textiles and offer the groundbreaking potential for **natural, pigment-derived dyeing**. Simultaneously, utilizing **aquatic plants** such as the invasive water hyacinth transforms an ecological problem into a valuable resource. The harvested and processed fibers from these plants are versatile, suitable for clothing, home textiles, and durable vegan leather alternatives like Piñatex®. The shift to these bio-fibers promises a **profound reduction in resource consumption** and promotes a **circular economy** by repurposing waste and managing invasive species, thus marking a new and promising era for environmentally responsible fashion.

Introduction:

The fashion industry, a major contributor to global pollution, is undergoing a vital transformation. At the forefront of this change is the innovative extraction of biofiber's from surprising sources: algae and water plants. These novel, bio-based materials offer a regenerative and circular alternative, promising to significantly reduce the environmental footprint of our clothing (Spagnuolo, C., & Bodelier, P., 2023).

The Urgent Need for Sustainable Textiles:

Traditional textiles, both natural and synthetic, impose a heavy burden on our planet. Conventional cotton demands vast amounts of freshwater, agricultural land, and often relies on chemical pesticides and fertilizers. Meanwhile, synthetic fibers like polyester and nylon, derived from petroleum, are a primary source of non-biodegradable microplastic pollution in our oceans. The need for a sustainable paradigm shift is undeniable (Anonymous, 2025).

Algae-Based Fibers: The Ocean's Answer to Fashion

Algae, encompassing both microalgae and macroalgae (seaweed), are remarkably sustainable resources. They grow rapidly, absorb CO2, don't require arable land or fresh water, and are fully biodegradable (Baghel, R. S., Reddy, C. R. K., & Jha, B., 2023).

Extraction Process:

1. **Cultivation and Harvesting:** Algae are cultivated in controlled, closed-loop systems, often using saltwater and solar energy, or harvested directly from marine environments.

2. **Processing:** The harvested biomass is washed and then processed into a liquid solution or pulp. This typically involves solvent extractions to remove pigments, lipids, and other non-cellulose components, leaving a cellulose-rich fraction or a biopolymer like alginate.

3. **Fiber Formation:**
   - **Blending:** The liquid algae solution can be combined with other plant-derived cellulose (e.g., from eucalyptus or beech pulp) using methods like the Lyocell process.
   - **Direct Yarn Production:** Some companies produce durable yarn directly from processed kelp.
   - **Natural Dyeing:** A groundbreaking innovation is the ability for the fiber to inherit color directly from the algae's natural pigments, eliminating the need for harmful synthetic dyes and their associated water and chemical usage.

Applications of Algae-Based Fibers:

Algae-derived fibers are finding their way into various applications:

- **Apparel and Clothing:** Spun into yarns for diverse clothing items, offering softness, breathability, and durability.
- **Natural Dyes and Coatings:** Algae's rich pigments provide non-toxic, chemical-free dyes and textile coatings.
- **Functional Textiles:** Natural properties like moisture management, UV protection, and antimicrobial activity make them ideal for activewear.

- **Biomaterials in Medical Fields:** Their biocompatibility makes them suitable for wound dressings and biodegradable implants.

- **Photosynthetic Fabrics:** Innovative "biogarmentry" fabrics are being developed using living algae, actively purifying the air.

Water Plant-Based Fibers: Turning Problems into Solutions

Aquatic plants, such as the invasive water hyacinth, are being explored as valuable, renewable fiber sources. Their utilization helps manage ecological problems caused by their overgrowth while providing a sustainable material (Rajendran, S., Scelsi, L., & Hodzic, A., 2024).

Extraction Process:

1. **Harvesting and Pre-processing:** Plants are harvested, washed, and sun-dried to maintain pliability.

2. **Fiber Isolation:** Stems are split, pith removed, and remaining strands undergo mechanical and chemical treatments (e.g., alkali solutions) to separate fibers from lignin and hemicellulose.

3. **Post-processing:** Fibers are washed, dried, and spun into yarn, often blended with other fibers to enhance durability.

Applications of Water Plant Fibers:

- **Clothing and Home Textiles:** Used for shirts, dresses, curtains, upholstery, and bed covers, often blended for enhanced properties.

- **Fashion Accessories and Vegan Leather:** Woven or braided into hats, bags, wallets, and shoes. Pineapple leaf fiber (Piñatex®) is a prime example of a durable, vegan leather alternative (Ananas Anam., 2025).

- **Handicrafts and Ropes:** Their tough, flexible nature makes them suitable for traditional crafts, mats, and ropes.

- **Composite Materials:** Used as reinforcement in composite materials for non-fashion applications.

The Sustainability Impact: A Brighter Future

The shift to biofibre's from algae and water plants offers profound environmental advantages:

- **Reduced Resource Use:** Significantly less water and energy are required compared to conventional materials.

- **Waste Reduction & Circularity:** These fibers repurpose agricultural waste or manage invasive species, promoting a circular economy.

Conclusion:

The innovative extraction of bio-fibers from algae and water plants represents a **transformative and necessary leap** toward a sustainable fashion industry. The current reliance on water-intensive cotton and petroleum-derived synthetics is no longer tenable given the planetary crisis. Algae and aquatic plants offer **inherently regenerative solutions**—algae through their minimal resource requirements and sequestration, and water plants by valorizing invasive biomass. The resulting bio-based textiles are not merely substitutes; they are **functional and circular materials** offering benefits like natural dyeing, antimicrobial properties, and superior biocompatibility for medical applications. By turning ocean and aquatic resources into fashionable and functional textiles, this new era of material science provides the industry with a clear path to significantly reduce its environmental footprint, foster waste reduction, and establish a truly **circular and earth-friendly supply chain**. Further research and commercial scaling of these technologies are paramount to realizing the full potential of these aquatic resources for a brighter, cleaner future in fashion.

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DIGITAL FARMERS, GREEN FUTURES

Introduction

Indian agriculture is entering a new era. On one side, farmers are facing **climate shocks**—erratic rainfall, more frequent droughts, heat waves and floods. A policy paper drawing on India's Economic Survey estimated that climate-related disasters account for **around 77% of the country's total economic losses from natural disasters**, costing roughly **USD 9–10 billion every year**.

On the other side, rural India is becoming **digitally connected**. Smartphones, cheap data and social media have turned the traditional "chaupal" into a **digital space**. Farmers now participate in WhatsApp groups, follow YouTube channels, join Facebook pages and consult mobile apps. A recent study on Indian farmers' social media use reported that **about 84% of the sampled farmers used mobile phones or social media for agricultural information**, and more than **60% relied specifically on WhatsApp and YouTube**.

At the same time, the Indian government and research institutions are investing heavily in **climate-resilient and green technologies**—stress-tolerant varieties, micro-irrigation, improved livestock management, water harvesting and solar-powered pumps. ICAR's flagship programme **National Innovations in Climate Resilient Agriculture (NICRA)**, launched in 2011, works in climatically vulnerable regions to demonstrate such technologies and build farmers' capacities.

Together, these forces are giving rise to **climate-smart farmer communities**—groups of farmers who learn collectively through digital and physical platforms, adopt climate-resilient practices and gradually transform their local rural agri-economy.

What Is a Climate-Smart Farmer Community?

The concept of **Climate-Smart Agriculture (CSA)**, promoted by FAO and adapted in India, rests on three pillars:

1. **Sustainably increasing productivity and income**
2. **Adapting and building resilience to climate change**
3. **Reducing greenhouse gas emissions wherever possible**

When these principles are adopted **collectively** at village or cluster level, we see the emergence of climate-smart farmer communities. They are typically characterised by:

- **High information connectivity** – social media, advisory apps, helplines, Kisan Call Centres and extension networks
- **Collective learning** – farmer field schools, group demonstrations, WhatsApp clusters and discussion groups
- **Green technologies** – water-saving irrigation, solar pumps, climate-resilient varieties, soil and water conservation, integrated crop–livestock systems
- **Economic reorientation** – diversification into less risky crops, allied activities, green value chains and rural enterprises

In India, **NICRA villages**, climate-resilient agriculture projects and **Farmer Producer Organisations (FPOs)** are important institutional spaces where such communities are slowly developing.

Climate-Smart Snapshot: Key Facts

- **Climate loss**: Climate-related disasters are estimated to contribute **about 75–80% of India's total economic losses** from natural disasters, amounting to roughly **USD 9–10 billion per year**.
- **Digital farmers**: Surveys show that **over 80% of sampled smartphone-owning farmers** use mobile phones or social media for agricultural information, especially **WhatsApp and YouTube**.
- **Irrigation energy**: Agricultural pumps consume around **25% of India's total electricity** and about **12% of diesel use (over 4 billion litres per year)**—a huge opportunity for solar and efficient irrigation.
- **NICRA reach**: ICAR's NICRA project has introduced climate-resilient practices in **hundreds of vulnerable villages** and trained **lakhs of farmers and stakeholders**.

Connected phones, smarter fields: climate-smart communities are quietly changing Indian agriculture.

Social Media: The New Layer of Extension

Across villages, social media is becoming a powerful **information layer**:

- Farmers share **photos of pests, nutrient deficiencies or weather damage** in WhatsApp groups and seek instant advice.
- YouTube videos demonstrate **drip installation, mulching, organic inputs, solar pump operation and climate-resilient seed varieties**.
- Live sessions by KVKs, universities, NGOs and agri-tech startups allow farmers to listen, ask questions and watch demonstrations without leaving their villages.

An experimental study on "social (media) learning" among Indian farmers showed that online information exchange **significantly increased their investment in productivity-enhancing inputs**, even though income effects were more visible only in the longer term.

However, this digital shift comes with risks:

- **Misinformation and unverified advice**
- **Commercial bias**, where product promotion is disguised as neutral guidance
- A persistent **digital divide**: women, older farmers and poorer households may have less access or confidence online

Therefore, social media works best when it is **anchored to credible extension systems** that can validate and correct the information flow.

Extension Platforms: Linking Science and Communities

Formal **agricultural extension systems**—State Agriculture Departments, KVKs, Agricultural

Universities, ATMA, NGOs and FPOs—remain central to the climate-smart transition.

ICAR's **NICRA** project, for example, covers climate-vulnerable villages across India, demonstrating:

- Drought- and heat-tolerant crop varieties
- Farm ponds, check dams and water harvesting structures
- Efficient irrigation (drip, sprinkler) and mulching
- Fodder development and improved livestock shelters

Official updates indicate that NICRA has supported and trained **lakhs of farmers** in climate-resilient agriculture.

Extension platforms contribute by:

1. **Assessing and refining technologies** through research trials and on-farm testing
2. **Building capacity** through trainings, field schools and exposure visits
3. Providing **climate services** via SMS, apps and call centres
4. Supporting **institutions** such as SHGs, FPOs and water user associations

Many KVKs now maintain **YouTube channels and WhatsApp groups**, directly connecting formal science with farmers' digital spaces.

Green Technologies: The Hardware of Climate Smartness

Green technologies reduce environmental stress while improving farm resilience and income. Under NICRA and related schemes, promoted technologies include:

- **Drought-/heat-tolerant varieties** and stress-resilient livestock breeds
- **Water harvesting** (farm ponds, check dams, recharge measures)
- **Micro-irrigation** systems (drip and sprinkler) and mulching
- Improved crop residue management and conservation agriculture

Macro-level studies on India show that climate-smart practices like **System of Rice Intensification (SRI)** and **System of Wheat Intensification (SWI)** can deliver **higher economy-wide benefits with lower greenhouse gas emissions and water footprint** than conventional practices.

Irrigation is a major energy consumer in agriculture: pumps account for roughly **25% of India's electricity use and 12% of diesel consumption**. Schemes such as **PM-KUSUM** seek to solarise these pumps and add grid-connected solar generation. Analysis suggests that when **solar pumps are bundled with micro-irrigation and groundwater recharge**, they significantly improve water-use efficiency and climate resilience.

The economic effects at community level include:

- **Lower input costs** (diesel, electricity, water, sometimes fertiliser)
- **Reduced climate risk** through better water control and resilient technologies
- **More stable or higher incomes** via diversification and productivity gains
- New **rural enterprises**—solar pump leasing, custom hiring centres, repair and advisory services

When the Three Pillars Work Together

Climate-smart farmer communities emerge where three pillars interact:

1. **Social media and digital platforms** spread awareness, success stories and peer learning.
2. **Extension systems** validate information, adapt technologies to local conditions and provide training.
3. **Green technologies** offer the physical tools to change farming practices.

A typical pathway might look like this:

- A farmer sees a YouTube video on **drip irrigation or solar pumps**
- The idea is discussed in a **WhatsApp group**, where others share experiences and contacts
- The farmer attends a **KVK or NICRA demonstration** and learns technical details
- With information on subsidies like **micro-irrigation support or PM-KUSUM**, the farmer invests
- After success, the farmer shares photos and videos back on social media, inspiring others

Over time, such cycles build **networks of climate-smart farmers**—a powerful route for scaling climate-resilient agriculture and locally led adaptation.

Challenges and the Way Forward

Despite clear benefits, several challenges remain:

- **Digital inequality**: Not all farmers—especially women, older and poorer farmers—enjoy equal access to smartphones, internet or digital skills.
- **Cost and access barriers**: Even with subsidies, solar pumps, drip systems and protected cultivation can be expensive for smallholders.
- **Coordination gaps**: Climate-smart agriculture requires collaboration between multiple departments—agriculture, water, energy, rural development. Fragmented schemes can confuse farmers and reduce impact.
- **Gender and social equity**: Women farmers are central to adaptation but often lack recognition, land rights and directaccess to extension and finance.

To strengthen climate-smart farmer communities, India needs to:

- Scale up climate-resilient programmes like **NICRA** with robust monitoring of social and economic outcomes
- Integrate **digital and conventional extension**, ensuring that scientific content dominates the online space
- Provide **targeted support for green technologies** with a focus on small and marginal farmers
- Invest in **climate services** (local weather forecasts, pest/disease early warning) delivered via mobile platforms
- Train **rural women and youth** as "climate-smart community champions" and digital facilitators

Conclusion

Climate change is reshaping Indian agriculture—but farmers are not passive victims. Through a combination of **smartphones, strong extension and smart green technologies**, **climate-smart farmer communities** are beginning to appear across the country.

These communities are:

- **Digitally connected** through social media and mobile platforms
- **Scientifically supported** by extension and research institutions
- **Technologically empowered** by climate-resilient, resource-efficient innovations

Evidence from government reports, policy analyses and research studies suggests that such communities can **raise productivity, reduce climate risk, improve resource use and open new economic opportunities**. If India can bridge the digital divide, ensure credible and inclusive extension, and make green technologies widely accessible, climate-smart farmer communities will play a key role in **rebuilding rural agri-economies to be more resilient, inclusive and sustainable** in the years ahead.

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DESIGNING PROTECTIVE CLOTHING WITH ENHANCED UV RESISTANCE FOR OUTDOOR OCCUPATIONS

Abstract

Outdoor occupations such as construction, agriculture, landscaping, and fisheries expose workers to high levels of ultraviolet (UV) radiation from sunlight. Prolonged exposure to UV radiation can result in acute and chronic health issues, including sunburn, premature skin aging, and an increased risk of skin cancer. Designing protective clothing with enhanced UV resistance has therefore become an essential aspect of occupational health and safety. This article discusses the importance of UV-protective clothing, factors affecting UV resistance in textiles, materials and finishes used, design considerations, testing standards, and recent innovations aimed at improving UV protection for outdoor workers.

Introduction

Occupational exposure to ultraviolet radiation is a serious concern for individuals who spend extended periods outdoors. According to the World Health Organization (WHO), UV radiation is a significant environmental carcinogen that can damage the skin and eyes. Workers in outdoor sectors such as agriculture, construction, and sports are at particular risk. The use of protective clothing is a practical and effective method to minimize UV exposure. Designing garments with enhanced UV resistance involves more than simply covering the skin—it requires a careful balance of comfort, durability, breathability, and functionality while ensuring maximum UV protection. As awareness grows about the harmful effects of solar radiation, industries and researchers are increasingly focusing on innovative textile technologies that provide efficient, long-lasting, and sustainable UV protection.

Understanding UV Radiation and Its Effects

UV radiation is part of the electromagnetic spectrum emitted by the sun, divided into three types based on wavelength:

- UVA (315–400 nm): Penetrates deeply into the skin and causes aging and DNA damage.
- UVB (280–315 nm): Causes sunburn and is more likely to induce skin cancer.
- UVC (100–280 nm): Mostly absorbed by the Earth's atmosphere and does not reach the surface.

The level of UV radiation reaching workers depends on several factors such as geographical location, altitude, time of day, season, and surface reflection (from water, sand, or snow). Chronic exposure without proper protection can lead to health issues like photodermatoses, cataracts, and skin cancers. Hence, designing effective protective clothing is a critical component of occupational safety strategies.

Factors Influencing UV Protection in Textiles

The ability of a fabric to block UV rays is measured using the Ultraviolet Protection Factor (UPF). A higher UPF value indicates better protection. Several factors determine the UV resistance of textiles :Fiber Type: Polyester and nylon provide high UV resistance due to their compact structure. Cotton and linen are breathable but less UV-resistant unless treated.Fabric Construction: The weave or knit density significantly affects UV resistance. Tightly woven fabrics with smaller gaps between yarns block more UV rays.Color and Finishing: Darker colors absorb more UV radiation than lighter ones, and chemical finishes containing UV absorbers enhance blocking properties.

Moisture and Stretch: Wet or stretched fabrics offer reduced UV protection, so clothing must maintain performance under various conditions.

Materials and Finishes for UV-Protective Clothing

Modern textile engineering offers several approaches to improving UV protection through material selection and surface finishing. High-Performance Fibers: Advanced fibers such as microfibers, polyester blends, and nylon 6,6 are used for UV-protective clothing due to their tight structures and ability to incorporate UV-blocking additives during spinning.UV-Absorbing Finishes: Applying UV-absorbing chemicals onto the fabric surface enhances protection. Common agents include benzotriazole and benzophenone derivatives, titanium dioxide (TiO_2), and zinc oxide (ZnO) nanoparticles. Natural and Eco-Friendly Treatments: Researchers are developing eco-friendly UV-blocking treatments using plant-based extracts such as flavonoids, lignin, and tannins.

Design Considerations for Outdoor Protective Clothing

The success of UV-protective clothing depends not only on the fabric's properties but also on the garment's design and functionality. Coverage and Fit: Garments should cover as much skin as possible—long sleeves, high collars, and wide-brimmed hats are essential, but comfort must not be compromised. Breathability and Comfort: Fabrics must allow air circulation and moisture wicking. Advanced textiles like micro-perforated polyester help maintain thermal comfort. Durability and Maintenance: Protective clothing should retain UV resistance after multiple washes and exposure to sunlight. Aesthetic and Functional Design: Workers are more likely to wear protective clothing if it is comfortable and visually appealing.

Testing and Evaluation of UV Protection

UV protection levels are evaluated using the Ultraviolet Protection Factor (UPF) rating system. According to AS/NZS 4399:2017 and AATCC 183, UPF is calculated by measuring the ratio of UV radiation transmitted through the fabric to the total incident radiation.

UPF Rating	Protection Category	UV Blocked (%)
15–24	Good	93.3–95.9
25–39	Very Good	96.0–97.4
40–50+	Excellent	97.5–98+

For occupational use, fabrics with a UPF rating of 40+ are recommended. Regular testing ensures that UV protection remains effective after laundering.

Innovations and Future Trends

Nanotechnology: Nanoparticles such as TiO_2 and ZnO are incorporated into fibers for permanent UV protection without affecting texture.Smart Textiles: Smart fabrics that can change color or alert wearers to UV levels are being developed to increase awareness.Sustainable Solutions: Future research focuses on biodegradable fibers and natural UV blockers for eco-friendly protection.

Conclusion

Designing protective clothing with enhanced UV resistance is essential for safeguarding outdoor workers from harmful solar radiation. The effectiveness depends on fiber type, fabric structure, finishes, and design. Integrating innovative materials such as nanoparticles and natural extracts boosts protection while maintaining comfort and sustainability.

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GENE EDITING VS TRADITIONAL BREEDING: WHAT'S THE FUTURE

Abstract

Agricultural innovation is entering a transformative era where traditional breeding and modern gene editing stand as two complementary pillars of crop improvement. Traditional breeding, though time-tested and foundational, is often constrained by its lengthy timelines and limited precision. In contrast, gene editing technologies such as CRISPR–Cas9 offer targeted, rapid, and efficient modification of plant genomes, enabling traits like stress tolerance, higher yield, and resource efficiency. This paper examines the comparative strengths, limitations, and ethical implications of both approaches. While traditional breeding sustains genetic diversity and public trust, gene editing accelerates genetic advancement and adaptation to emerging challenges such as climate change and food insecurity. Rather than positioning them in opposition, the study advocates for an integrative model—leveraging traditional breeding's diversity base with gene editing's precision—to achieve sustainable, ethical, and resilient agricultural systems. The future of crop improvement lies in harmonizing heritage with innovation to responsibly meet global food demands.

Keywords: Gene editing, Traditional breeding, CRISPR–Cas9, Crop improvement, Agricultural biotechnology, Sustainable agriculture

Introduction

Innovation and tradition have always coexisted in the agricultural industry. As farmers and scientists, our journey has been nothing short of fascinating, from hand-picking the best grains for the upcoming sowing season to now editing genes in a lab. Traditional breeding and gene editing are two potent tools that are at the centre of one of the most discussed topics in Agri-science today. Which of these will lead us into the future? Or do we require both?

I recall standing in the centre of a paddy trial plot under a scorching sun during my fieldwork in the second year of my degree program, looking at the differences between genotypes. I realized how much intuition and patience traditional breeding requires.

But can tradition stand alone as we confront global issues like food insecurity, climate change, and the loss of arable land?

Let's take a closer look

Traditional Breeding: The Old Reliable

Like the slow, consistent tortoise in a race, traditional plant breeding is It entails crossing over several generations from plants with the most desirable features—perhaps yield, drought resistance, or pest tolerance. From robust wheat stalks to golden rice fields, this approach has blessed us with all the crops we depend on now.

Still, the process is more complicated than it sounds. Years, occasionally decades of trial and error are involved. In order to separate a single characteristic, breeders have marked rows of plants, noting minute variations season after season. That is admirable effort. But in the fast-paced environment of today, it's difficult not to question: is time a luxury we still could afford?

Expert Voice: "Modern agricultural genetic backbone is formed from traditional breeding. Still, its shortcomings in speed and accuracy are difficult to overlook."

Senior Geneticist Dr S.K. Singh of ICAR-IARI

Gene Editing: The Future is Now

Imagine now that, rather than waiting years for the correct features to show up, you directly enter the DNA of a plant and modify it—akin to proofreading a document. For you that is **gene editing**. Precision cutting and modification of DNA made possible by technologies such as **CRISpen-Cas9** enables scientists to add or remove features without involving foreign genes.

Though it sounds futuristic, this is already happening. Tomatoes edited genetically to withstand browning? Examine. Rice requiring thirty percent less water? On the road. wheat free of gluten? Already under trials.

Real Data: Under stress like drought or salinity, gene-edited crops could boost yield by up to 25% according to a 2022 National Academy of Sciences study.

Expert Voice: "We can achieve a level of accuracy with gene editing that is just not possible with conventional techniques. But we have to be cautious.

— CRISPR co-inventor Dr. Jennifer Doudna

However, productivity isn't the only factor. Additionally, gene editing can help crops become more environmentally friendly by reducing their reliance on pesticides and fertilizers.

But Is It Safe? And More Importantly—Is It Ethical?

This is where the situation becomes complex. To be honest, I understand that not everyone is in Favor of gene editing.

The idea of "messing with nature" is fraught with anxiety. The concept still raises ethical concerns, despite the fact that gene editing differs from genetically modified organisms (GMOs) in that it does not always involve foreign DNA. Concerns include corporate control over seed patents, ecological disruption, and unforeseen consequences.

This is not to argue that conventional breeding is perfect. It has also involved heavy hybridization and radiation-based mutation, both of which are inherently unnatural.

Thus, the inquiry is not merely a scientific one. It's communal. It's sentimental. It’s ethical.

Survey Insight: According to a 2023 **Pew Research Center** report, **62%** of respondents supported gene editing for disease resistance in plants, but only **38%** approved of its use in livestock.

Comparing the Two: Head-to-Head

Feature	Traditional breeding	Gene Editing
Time	5-20 years	1-3 years
Precision	Low	Very high
Genetic Diversity	Broad	Narrow (risk of genetic uniformity)
Public Trust	High	Moderate to low
Cost	Lower input	Higher but may reduce input long terms

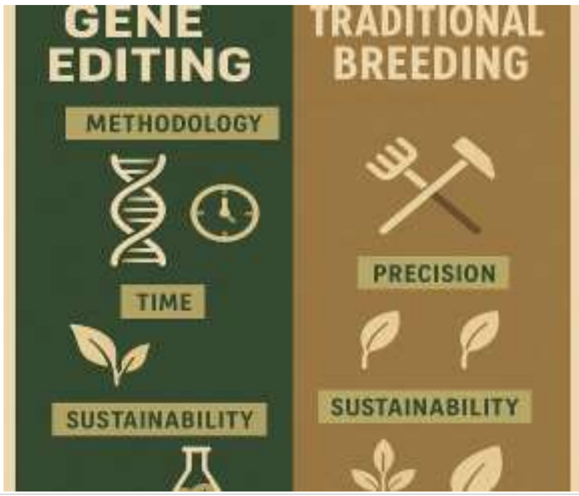
Neither is perfect. But both have roles to play.

Why Not Both?

Perhaps the questions we are posing are inappropriate. It is about synergy, not about choosing sides. Traditional breeding reminds us to work with what nature provides, to respect natural diversity, and to practice patient observation. Conversely, gene editing prepares us to rapidly and precisely meet pressing challenges. Imagine combining both: beginning with a wide, varied gene pool from conventional approaches and applying gene editing just when absolutely necessary—to fix a bottleneck, resist a new pest, or adapt to a sudden climate change. Science fiction is not what we are here discussing. Smart agriculture is what that is.

Final Thoughts: Cultivating a Balanced Future

Studying agriculture in the middle of fieldwork and classroom theory, I see the future in using both wisely rather than in deciding one approach over the other. Right now, what we actually need is: Clear laws help consumers and farmers to trust the technology. Public education helps to dispel false ideas and disseminate correct knowledge. Inclusive policies whereby small farmers have access—not only companies. One does not want to substitute a lab coat for the farmer. It's to equip the farmer with the finest tools—be they genes refined in a lab or seeds cultivated over



generations. What therefore is the direction of breeding? That is a handshake between the past and the present. One in which modern science and ancient knowledge cooperate to ethically and sustainably feed the planet.

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DESIGNING FUNCTIONAL LIVESTOCK WEAR WITH FASHION-INSPIRED INNOVATION

Introduction:

The concept of livestock wear has traditionally focused on functionality — providing protection from environmental hazards, pests, or injuries. However, with the growing intersection between design innovation and agricultural technology, there is increasing potential to integrate fashion aesthetics into functional livestock apparel. This paper explores how design thinking and fashion innovation can be applied to create livestock wear that is both practical and aesthetically enhanced. By examining materials, ergonomics, sustainability, and cultural influences, the study highlights how the principles of fashion design can enhance comfort, identification, and welfare in animals while also offering commercial and branding opportunities for farmers and rural entrepreneurs.

Livestock plays a vital role in rural and agricultural economies, contributing to food security, income, and social value. While human clothing has evolved through centuries of innovation combining functionality and fashion, animal clothing remains limited to utilitarian purposes — such as protection from weather, insect bites, or injury. However, the emerging field of livestock wear design opens new avenues for integrating functional technology with fashion aesthetics.

The confluence of agricultural technology (Agri Tech) and wearable textiles presents a significant, yet underexplored, opportunity in livestock management. Traditional livestock coverings primarily focus on basic protection, often neglecting ergonomic fit, advanced functionality, and contemporary design aesthetics. This research, titled "Designing Functional Livestock Wear with Fashion-Inspired Innovation," seeks to establish a rigorous, systematic methodology for creating next-generation livestock apparel. This apparel will integrate advanced features like sensor technology, thermal regulation, and durability, all while adopting a fashion-inspired design approach to enhance user acceptance, brand identity, and overall practicality (Smith & Jones, 2023).

RESEARCH OBJECTIVES

The key objectives of this study are:

1. **To analyze the functional needs of livestock** that can be addressed through wearable designs.
2. **To explore fashion design principles** applicable to livestock wear.
3. **To identify sustainable materials and technologies** suitable for animal apparel.
4. **To examine the socio-economic and cultural implications** of fashion-inspired livestock wear.

The research uses a qualitative, design-based methodology that includes case studies, material experimentation, and user-centered design. This approach supports understanding livestock needs while developing functional yet aesthetically designed wearables.

Observation

The first phase involves direct observation of livestock in their natural environment—farms, stables, and grazing fields.
This step focuses on understanding:

- **Animal behavior:** resting, walking, feeding, interaction with other animals.
- **Environmental exposure:** sunlight, rain, cold winds, mud, and uneven terrain.
- **Discomfort indicators:** skin rashes, scratching, restlessness, heat stress, or irritation.
- **Current clothing used by farmers,** if any, along with their limitations.

Through these observations, recurring issues such as heat stress, insect bites, chafing from poorly fitted covers, and inadequate weather protection were identified. These insights form the foundation of the design requirements.

Material Research

In the second phase, various natural and synthetic materials were explored to determine their suitability for livestock wear.
Materials Studied

- **Jute blends** – durability and breathability
- **Organic cotton** – comfort and skin safety
- **Recycled polyester & technical fleece** – insulation and moisture-wicking
- **Rip-stop nylon** – weather resistance and tear strength

Material Evaluation Criteria

Comfort and Breathability Tests
Durability Assessments for Outdoor Use:

- Moisture absorption and drying time
- Weight analysis to ensure the garment does not burden the animal
- Evaluation of materials that offer thermal comfort, flexibility, hygiene, and long-term resilience

Design Experimentation: This stage applies fashion design principles to livestock wear.
Includes:

- Sketching prototypes inspired by jackets, capes, padded coats, and ergonomic sportswear
- Pattern manipulation to suit the anatomy of cattle, horses, goats, and camels
- Motif and color selection focusing on aesthetics, visibility, and safety
- 3D mock-ups or draping on mannequins or animals (with supervision)
- Zonal mapping to identify areas needing padding, ventilation, or reinforcement

Fashion elements such as pleats for movement, adjustable closures, seam placement, insulation panels, and lightweight layering are adapted for animal comfort.

Feedback Analysis

In the final phase, prototypes and material samples are evaluated by:

- **Farmers and livestock owners:** ease of use, durability, practicality
- **Veterinarians and animal care experts:** comfort, behavior changes, health effects
- **Fashion designers and textile specialists:** material performance and construction quality

Feedback helps refine:

- Fit and size
- Closure systems
- Comfort zones
- Weight balance
- Maintenance requirements

This collaborative approach ensures designs are functional, sustainable, user-friendly, and suitable

for livestock.

Functional Design Aspects: Functional livestock wear serves the needs of animals living in diverse agricultural environments. Unlike human clothing, livestock apparel must prioritize protection, comfort, mobility and safety.

Weather Protection: Livestock face extreme weather, affecting their health and productivity.

Cold Weather

- Animals may suffer from cold stress.
- Insulated coats (quilted polyester, fleece, wool blends) retain body heat.
- They reduce energy loss and prevent illness.

Hot Climates

- UV-resistant covers protect from sunburn, heat stress, and dehydration.
- Lightweight mesh fabrics allow airflow and cooling.

Rain & Humidity

- Water-resistant fabrics keep animals dry.
- Breathable waterproof textiles prevent fungal infections and irritation.

Health and Safety Features: Livestock wear helps prevent injuries and infections.

- **Anti-microbial fabrics:** prevent bacterial buildup and maintain hygiene
- **Reflective strips:** improve visibility near fields or roads
- **Insect-repellent finishes:** protect animals from mosquitoes, ticks, and flies

Ergonomic Fit & Movement Flexibility

- **Adjustable straps** offer custom fitting
- **Contour shaping** aligns with the animal's body structure
- **Lightweight materials** reduce discomfort and maintain mobility

Application of Fashion Design Principles

- **Balance:** equal weight distribution
- **Proportion:** appropriate sizing and fit
- **Rhythm:** repeated seams or patterns
- **Harmony:** cohesive blend of colors, shapes, and fabrics

These principles enhance both function and appearance.

Fashion-Inspired Innovation

Use of Color Psychology

- Earth tones create calmness
- Soft pastels reduce stress
- Bright colors improve visibility and support farm branding

Cultural Motifs and Regional Identity

Integrating regional textile traditions adds cultural value:

- Rajasthan: mirror work, block prints
- Gujarat: Bandhani, Kutch embroidery
- South India: temple motifs
- Northeast: tribal patterns

Smart Textiles and Technology

Innovations include:

- Temperature sensors
- Motion sensors
- GPS tracking
- Stress and biometric indicators

Benefits:

- Real-time health monitoring
- Reduced veterinary costs
- Increased productivity

Sustainability and Material Considerations

Eco-Friendly Materials

- Organic cotton
- Bamboo fiber
- Hemp
- Recycled polyester

Natural Dyeing: Using dyes from turmeric, indigo, henna, madder root, and marigold reduces environmental harm.

Biodegradability: Biodegradable materials reduce waste and support circular design.

Cultural and Economic Dimensions

Cultural Significance

Livestock wear enhances identity in festivals, ceremonies, and rural traditions.

Economic Opportunities

Livestock wear can support rural livelihoods through:

- Local tailoring units
- Women's SHGs
- Craft clusters
- Regional artisans

Market Potential & Agri-Tourism

Visually appealing livestock wear supports:

- Farm branding
- Tourism
- Photography
- Premium livestock marketing

Conclusion

Designing functional livestock wear using fashion-inspired innovation bridges utility and creativity. This research shows that applying fashion methodology—material innovation, user-centered design, and aesthetic exploration—can transform livestock wear into a meaningful tool for comfort, safety, cultural identity, and environmental responsibility.

Field observations confirm that livestock face environmental and physiological challenges that can be addressed through improved garment design. Smart-textile integration adds new value by enabling real-time monitoring, improving health management, and reducing long-term costs. Culturally enriched designs empower rural artisans and contribute to livelihoods, while sustainable materials promote environmental stewardship. As the sector evolves, future research should explore wearable technologies, 3D design tools, bio-fabrics, and accessible commercialization models.

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"EFFICIENCY OF ANTI MÜLLERIAN HORMONE TO PREDICT REPRODUCTIVE EFFICIENCY IN BOVINE"

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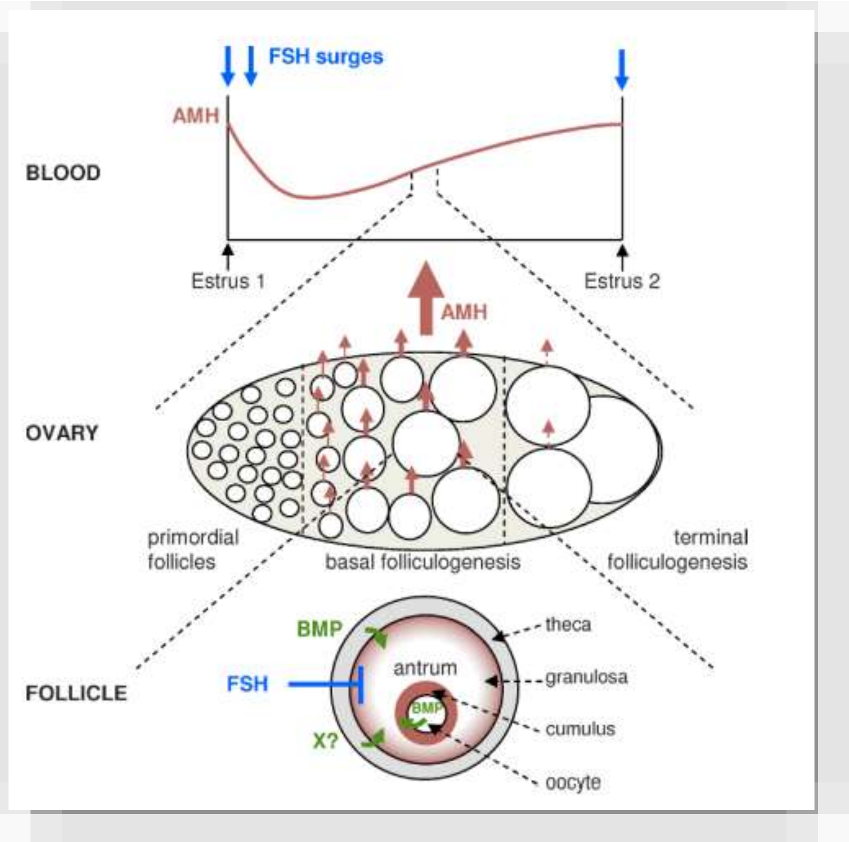
What is AMH?

Anti-Müllerian hormone (AMH) is a glycoprotein of 140 kDa belonging to the transforming growth factor of beta family that is expresses only in the gonads (Cate *et al*., 1986). It is also known as Müllerian Inhibiting Substance. AMH synthesized by Sertoli cells of the testes in the male and by granulosa cells of pre-antral as well as small antral follicles and *cumulus oophorus* in females (Visser *et al*., 2006).

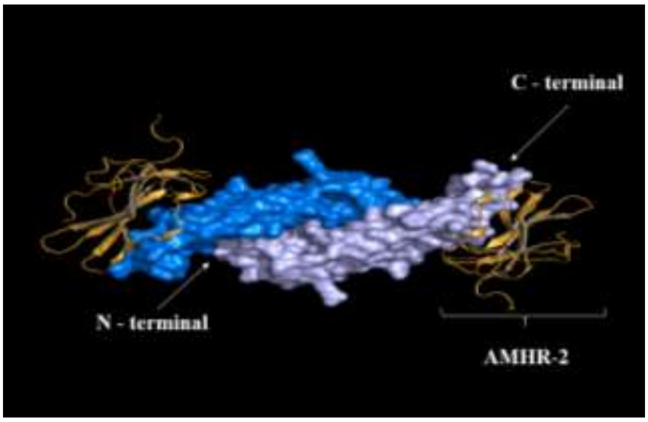


Presently, AMH is the best endocrine marker of the ovarian reserve in human, in mouse and recently the AMH is also a reliable endocrine marker of the population of small antral gonadotropin responsive follicle in bovines. Low plasma AMH concentrations are indicative of ovarian aging in women. (Rico *et al.*, 2009).

How AMH was discovered?

Initial stage of fetal life the reproductive tract is sexually undifferentiated. Müllerian duct and Wolffian duct are the primordia in male and female, respectively. If testes are present Wolffian ducts persist and Müllerian ducts disappear. Testicular product distinct from testosterone is responsible for Müllerian regression. This experiment reveled separate factor **other than** testosterone is responsible calle Müllerian inhibitor, Müllerian Inhibiting Substance, Müllerian Inhibiting Factor or Anti-Müllerian Hormone (AMH; Jost, 1953)

Structure of AMH

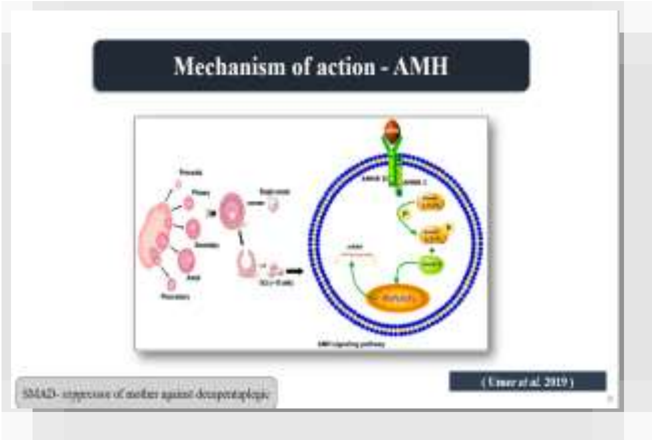


AMH consisting of two identical subunits; (1) N-terminal dimer (pro-region) and (2) C-terminal dimer (TGF-β domain). Carboxyl terminal fragment is biologically active. Amino terminal fragment is biologically inert. Location of gene is on chromosome seven and nine in cattle and buffalo, respectively (Maclaughlin *et al.*, 1992)

AMH receptors

AMH have two receptors. AMH receptor type-I (AMHRI) & type-II (AMH II) which exclusively found in granulosa cells. Receptors are found in greater quantities on small (5–8 mm) compared to large (13–24 mm) follicles (Poole *et al*., 2016).

Mechanism of action of AMH



AMH Ligand bind to AMH type II receptor which activate receptor-mediated phosphorylation and activating the type I receptor. Activated AMH-receptor complex causes phosphorylation of any one of smad 1, 5 or 8 proteins. These phosphorylated smad proteins may be termed as receptor specific smads or r-smads. Phosphorylated smad proteins combines with smad 4 protein and the complex thus formed translocate to the nucleus where it starts transcription of target gene (Umer *et al.*, 2019).

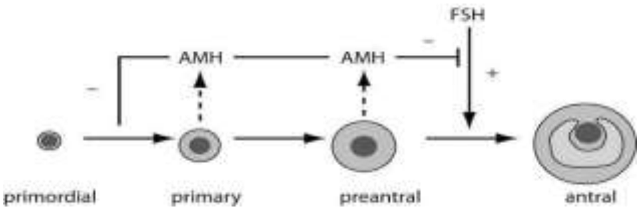
Application of AMH in Animal Reproduction

AMH is a consistent and useful biological marker of ovarian function. The success of assisted reproductive technology procedures can be predicted by measuring the AMH concentrations. In teratological aspects, AMH detection in peripheral circulation can serve as a tool for diagnosis of cryptorchidism and anorchia condition in males. Intact and spayed bitches can be distinguished by determining plasma AMH concentrations. It can also be used to detect ovarian remnant syndrome in bitches. In males, it can be used as a biomarker for detecting the status of Sertoli cells in males at puberty

Role of AMH

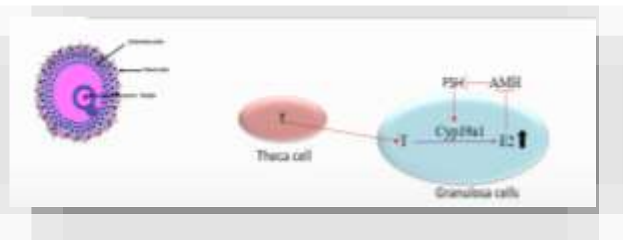
Cattle are born with a finite number of morphologically healthy follicles and oocytes in the ovaries called as ovarian reserve that decrease rapidly during aging and are never replenished. AMH expression initiated as soon as primordial follicle are recruited to grow into small pre antral follicle and its highest expression is observed in pre antral and small antral follicle. When there is no AMH, primordial follicle recruited faster which result in more growing follicle until the exhaustion of primary follicle pool at younger age (Durlinger *et al*., 1999)

Schematic model of AMH action in ovary



(Van houten *et al.* 2010)

Theca cells produce androgens and are transformed into estrogen by the aromatase system of granulosa cells under the influence of FSH. Estrogen down regulated AMH so follicles become more sensitive to FSH leading to increased estrogen production further follicular selection and subsequent ovulation in the normal ovary.



AMH plays two critical functional roles

1) Inhibits premature exhaustion of the follicular reserves
2) Reduces the sensitivity of the pre-antral and small antral follicles to FSH while modulating follicular development

AMH & Antral Follicle Count (AFC)

What is Antral Follicle Count?

The number of antral follicles determined during follicular waves termed as antral follicle count. AFC is directly proportional to total number of follicles in the ovary across all developmental stages (Ireland *et al*., 2008). AFC is highly variable among individuals but highly repeatable in same or consecutive estrus cycle within each animal (Burns *et al*., 2005). AFC is proportionally related to the size of the ovarian reserve. AMH secreted from these growing follicles has positive correlation with AFC (Ireland *et al*., 2008). Both AFC and AMH serve as a biomarkers for ovarian reserve (Rico *et al*., 2009). AMH is highly correlated with AFC during the estrous cycle (Ireland *et al*., 2008). High AMH 3–7 mm gonadotropin responsive follicles (Rico *et al*., 2009). In beef heifers circulating AMH concentrations. High (25 follicles): six fold; Intermediate (16–24 follicles); two fold; Low (15 follicles).

AMH & Oocyte Quality

Plasma AMH concentrations and ovarian AFC are positively correlated (Luciano *et al*., 2013). High AMH reflect healthy ovarian follicles with high fertility. A smaller ovary with very low ovarian reserve is indicated by decline in AMH concentrations in sub fertile cows (Ireland *et al*., 2011)

AMH during estrus cycle

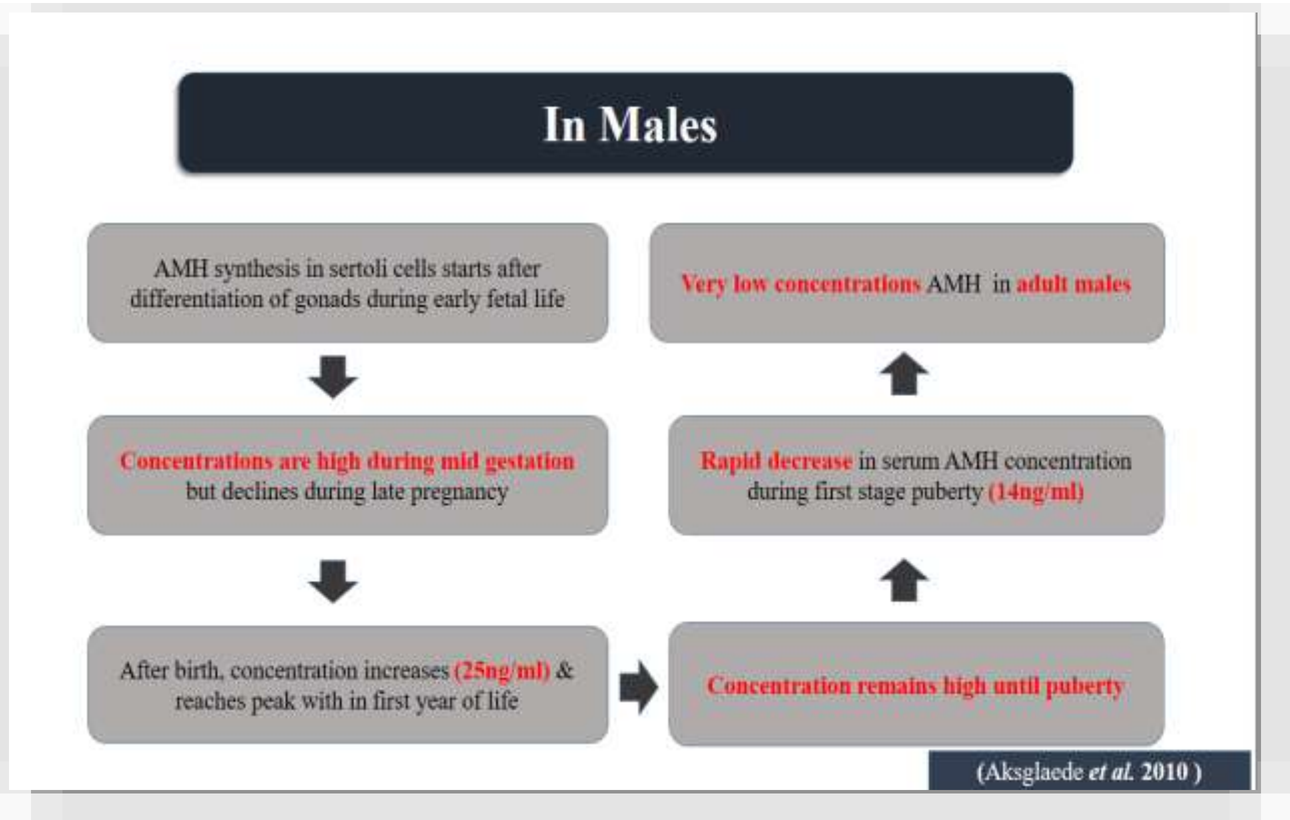
The AMH concentration different stages of synchronized estrous cycle. In proestrus: 133.2 ± 10.6 pg/ml, estrus: 132.7 ± 9.7 pg/ml, diestrus: 150.9 ± 10.6 pg/ml (Souza *et al*., 2015). AMH concentration vary minimum during same estrus cycle, on different days of two estrus cycle and subsequent estrus cycle. So AMH concentration can be determined with single blood sample. The mean concentration of AMH at estrus cycles Natural (0.0543 ± 0.01 ng/ml) vs Synchronized (0.0428 ± 0.01 ng/ml). Positive correlation between natural and synchronized estrus cycle. Correlation of AMH in natural & synchronized estrus cycle in bovine. Beef heifers has an increased ($P < 0.05$) concentration of AMH compared with dairy heifers. Beef- 0.0638 ± 0.01 ng/mL vs. Dairy: 0.0402 ± 0.01 ng/ml (Pfeiffer *et al*., 2014).

AMH & Assisted Reproductive Technologies (ARTs)

ART includes hormonal stimulation, AI, *in vitro* fertilization in cattle. Super-ovulatory response depends on number of primordial and growing follicles in ovarian follicular pool (Cushman *et al*., 1999). AMH is complementary to total number of antral follicles present in ovary (Singh *et al*., 2004).

AMH & ARTs

AMH can be used as a tool in selecting best donor cows for embryo production. Cows undergone repeated OPU sessions shows highly repeatable concentrations of AMH. Which enables them to become potential donors used for *in vitro* embryo production and improves outcome of embryo biotechnologies (Monniaux *et al.*, 2010).AMH cut-off values can be standardized by number of ova retrieved by repeated OPU sessions (Rico *et al.*, 2012). AFP of 3-7mm are highly responsive to gonadotropin treatment during superovulation. Low responding cows to superovulation treatment can be eliminated by standardized AMH cut-off values. Cows with high plasma AMH concentrations have large number of follicles available for aspiration (Gamarra *et al.*, 2014). AMH can predict the potent donors for IVEP before puberty. AMH: endocrine marker for



selection of donor young calves. Use of pre-pubertal calves as oocyte donor for in vitro embryo production reduce generation interval and improves embryonic biotechnologies (Souza *et al.*, 2015)

AMH & conception

High AMH have higher first service conception rate (Ireland *et al.*, 2011). Animal become pregnant early in the breeding season (Gobikrushanth *et al.*, 2018) and high pregnancy rate
(Ribeiro *et al.* 2014). Heifers with low plasma AMH concentrations have short productive herd life. Lower percentage to get pregnant as compared to other herd mates. Early culling due to poor productive and reproductive performance (Jimenez-Krassel *et al.*, 2015).

AMH and fertility

High fertile group have significant high AMH (162 ± 24.04 pg/ml) as comparedto low fertile group (93.90 ± 15.06 pg/ml). Cow with low AMH have longer days- open period, extended calving to conception interval, high repeat breeding incidence, No. of services per conception.

Concentration of AMH in males

Blood-testis barrier becomes functional at puberty so, It doesn't allows AMH to get infuse to peripheral circulation therefore low level of AMH in peripheral circulation at puberty (Fenichel *et al.*, 1999). Positive association between sertoli cell count and semen quality (Rajak *et al.*, 2016). Negative relation is reported between AMH and sertoli cell count. Bulls with reduced of AMH in peripheral circulation have good semen quality, thus AMH can be used as a biomarker for detecting the status of Sertoli cells in bulls.

Factors Affecting AMH

1. **Nutrition**
2. **Hormones**
3. **Age**
4. **Disease**
5. **Granulosa cells**

Nutrition

The ovarian follicle pool is ascertained during fetal life (Erickson, 1966). Restriction of diet has a significant impact on the ovarian reserves of their offspring, lower plasma AMH, lower AFC (Mossa *et al.*, 2013). High protein fed to cattle during gestation impaired the AFC in offspring.

2. Age

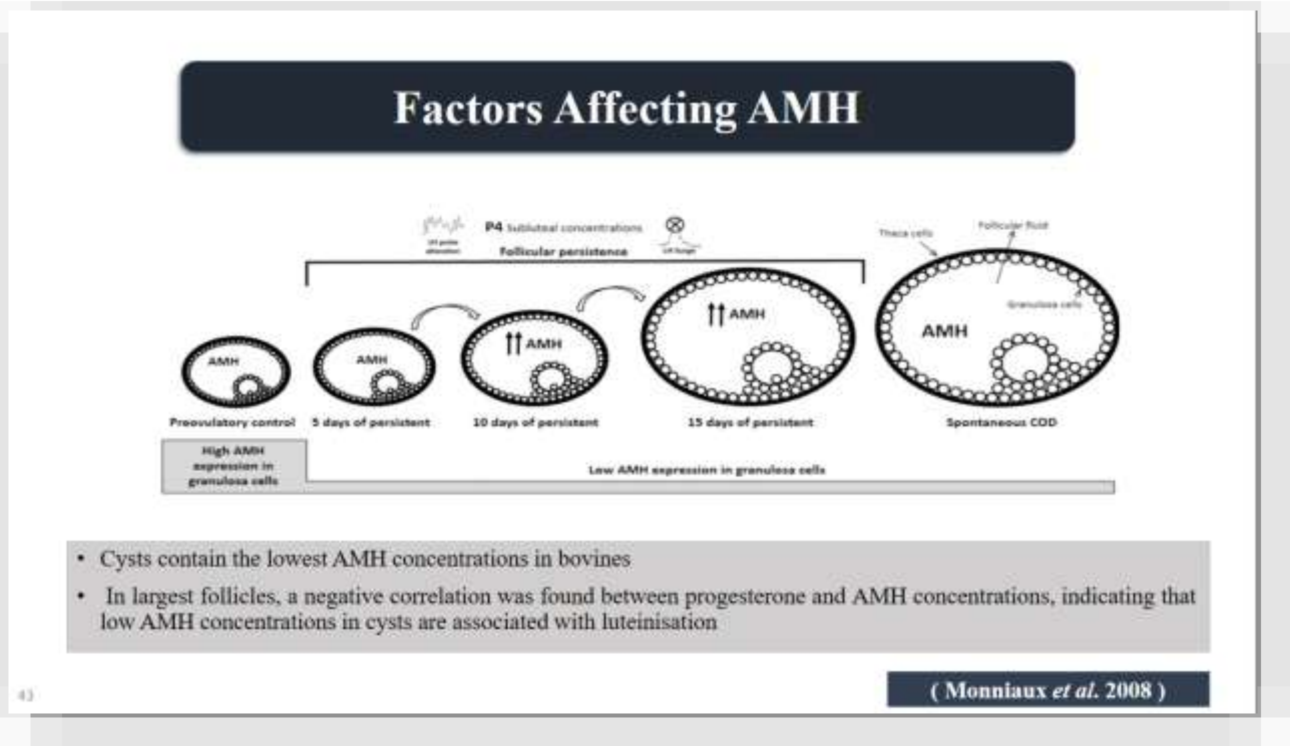
A study on Holstein cow reported no correlation between AMH and parity. Higher AMH concentration in cow on the second and third lactation compared to those on the first and fourth or greater lactation (Souza *et al.*, 2015). AMH concentration do not decline coincident with first few year of age in cattle (Ribeiro *et al.*, 2014). Like AFC, circulating AMH concentrations show a high correlation with the size of the ovarian reserve that declines with age. AMH is considered an excellent clinical indicator of ovarian aging in women.

3. Hormones

Endocrine-disrupting chemicals have a potential impact on the physiology and reproduction of animals.

4. Disease condition

AMH can be used as potential diagnostic tool for ovarian tumors in cows, mares, dogs and cats. AMH is a potential tool for monitoring bovine granulosa–theca cell tumor (GTCT) (Ali *et al.*, 2015). In women, polycystic ovarian syndrome (PCOS) showed a three-fold higher AMH level (Diaz *et al.*, 2018). Elevated AMH has been reported in bitches with luteinized follicular cysts. Cow suffered from chronic mammary gland infection have an impact on the offspring ovarian



reserves during gestation and have low AMH.

4. Granulosa cells

Cattle with a low AFC respond poorly to gonadotropin stimulation during superovulation (Ireland *et al*., 2008). Positive association between the response to superovulation and the ovarian reserve support the use of AMH as donor selection in embryo production (Scheetz *et al*., 2012).

Estimation of Anti-Müllerian Hormone by ELISA

Serum AMH concentration can be evaluated by using bovine AMH-ELISA kit; AL-114 test kit (AnshLabs), CEA228Bo test kit (Cloud-clone Corp). The cost of kit is 40,000 Rs., The cost of each sample will be approximately Rs.500.

Conclusions

AMH value used to predict ovarian stimulation in super-ovulatory treatment. The concentration of AMH is repeatable in same and consecutive estrus cycle so that single time AMH estimation can useful for determination of ovarian response. AMH has positive correction with AFC so it is helpful for field veterinarians to predict antral follicular population in contrast of USG. AMH level determine reproductive life span of animal. Animal with high AMH show high pregnancy rate.

Future Prospects

Breed specific ranges and cut-off value of AMH determined large number of cattle and buffaloes. AMH has potential to develop a rapid field side test or spot ELISA for instant determination. Overall performance of the AMH as a biomarker in cattle and buffaloes under Indian condition.

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FLORICULTURE-INSPIRED APPROACHES TO ECO-FRIENDLY FASHION DESIGNING

ABSTRACT:
This article examines the intersection of floriculture and sustainable fashion, exploring how botanical inspiration can guide eco-friendly design methodologies. By integrating principles of plant cultivation, natural aesthetics, and regenerative material use, fashion designers can create garments that are both environmentally responsible and artistically expressive. The study identifies key techniques such as eco-printing, plant-based dyeing, and modular floral design that bridge creative innovation with sustainability.
Keywords: Floriculture, Sustainable Fashion, Eco-friendly Design, Natural Dyes, Circular Fashion

INTRODUCTION:
The fashion industry has long turned to nature for artistic inspiration, particularly through the use of floral motifs and botanical themes. However, with the growing global emphasis on sustainability, the connection between floriculture—the cultivation and management of flowers—and fashion design is evolving from mere aesthetic influence to an eco-conscious practice. According to Fibre2Fashion (2024), nature-inspired fashion enhances both aesthetic appeal and environmental responsibility by aligning design innovation with ecological values.

FLORICULTURE- INSPIRES DESIGN APPROACH

Floriculture offers a framework for integrating natural processes into fashion design. Several eco-friendly approaches have emerged within this paradigm:

1 Botanical Motifs and Modular Floral Design :

Designers employ floral-inspired forms such as petals, stems, and organic patterns to produce modular garments that can be easily repaired, replaced, or reassembled. This concept aligns with modular textile systems studied by Taylor & Francis (2024), which promote product longevity and waste reduction.

Process :

1. Conceptual Research and Inspiration
2. Development of Botanical Motifs
3. Digitization and Stylization
4. Conversion into Modular Floral Design
5. Application in Eco-Friendly Fashion
6. Outcome

The process of converting **botanical motifs into modular floral design** begins with researching and sketching natural plant forms to create stylized floral motifs. These motifs are then digitized and refined for clarity, symmetry, and proportion. Next, the motifs are arranged within a defined unit or module, using repetition, rotation, and mirroring techniques to form a balanced, seamless floral pattern. This modular design can be repeated continuously and adapted for various applications such as printing, embroidery, or surface embellishment on eco-friendly fabrics. The outcome reflects a harmonious blend of nature-inspired artistry and sustainable fashion design.

2 Natural Dyes and Eco-Printing:

Floriculture facilitates the use of flowers and leaves for natural dye extraction and eco-printing, reducing dependency on harmful synthetic chemicals. Studies from the University of Bologna (2024) emphasize that eco-printing offers both aesthetic and ecological benefits by embedding plant imprints directly into fabrics without additional chemicals.

Process :

1. Collection of Natural Materials
2. Fabric Preparation (Mordanting)
3. Extraction of Natural Dyes
4. Dyeing Process
5. Eco-Printing Technique
6. Washing and Drying
7. Final Outcome

The **process of natural dyes and eco-printing** begins with collecting pigment-rich flowers and leaves, followed by preparing the fabric with a natural mordant to help colors bond. For natural dyeing, the plant materials are boiled to extract color, and the fabric is soaked in the dye bath to achieve soft, organic shades. In eco-printing, fresh petals and leaves are arranged on the fabric, tightly rolled, and steamed so their pigments transfer directly, creating unique botanical impressions. Finally, the fabric is rinsed, dried in shade, and lightly ironed to fix the colors, resulting in an eco-friendly, chemical-free textile surface.

3 Biophilic Design Narrative :

The philosophy of biophilic design—creating human-nature connections through materials and motifs—is strengthened by floriculture. Migration Letters (2023) reports that consumers form deeper emotional bonds with nature-inspired apparel, potentially leading to longer product life cycles.

Process:

1. Research and Inspiration
2. Concept Development
3. Concept Development
4. Design Creation and Application
5. Narrative and Storytelling
6. Final Outcome

The **process of Biophilic Design Narrative** begins with observing and studying nature to draw inspiration from its colors, forms, and textures. Designers then develop concepts that reflect a connection between humans and the natural world, creating mood boards and sketches based on organic patterns. Eco-friendly materials and natural color palettes are chosen to align with sustainability. These ideas are translated into designs through prints, textures, and silhouettes that capture nature's harmony. Finally, a storytelling approach is used to express the emotional and environmental message behind the designs, resulting in fashion that promotes both beauty and ecological balance.

4 Regenerative Material Sourcing and Circularity:

Fashion brands are increasingly adopting regenerative agricultural practices similar to floriculture. Vogue (2023) notes that plant-based fibre cultivation and soil restoration can be integrated into fashion supply chains to minimize ecological impact and foster circularity.

Process:

1. Regenerative Material Sourcing and Circularity
2. Sustainable Cultivation and Harvesting
3. Eco-Friendly Processing and Production
4. Product Design for Circularity
5. Recycling and Upcycling
6. End-of-Life and Regeneration
7. Final Outcome

The **process of regenerative material sourcing and circularity** begins with identifying renewable and eco-friendly raw materials such as organic cotton, hemp, or bamboo that restore rather than harm the environment. These materials are cultivated through sustainable farming practices that improve soil health and biodiversity. During production, non-toxic dyes, water-efficient methods, and waste-reducing techniques are used. Designers create garments with recyclability, repairability, and biodegradability in mind, promoting longer life cycles. Finally, old textiles are reused or composted, ensuring materials re-enter the natural or production cycle — achieving a **closed-loop system** that supports both sustainability and environmental regeneration.

5 Zero-Waste and Slow Fashion Patterns

Inspired by the life cycle of plants, designers are applying zero-waste cutting techniques and slow-fashion ethics. Wikipedia (2024) outlines how these approaches minimize textile waste and emphasize quality, longevity, and mindful consumption.

Process:

1. Concept Development
2. Pattern Planning and Fabric Utilization
3. Design and Construction
4. Production Process
5. Reuse and Upcycling
6. Consumer Awareness and Longevity
7. Final Outcome

The **process of zero-waste and slow fashion patterns** focuses on creating garments that minimize fabric waste and promote mindful, sustainable production. It begins with careful pattern planning to use every part of the fabric through geometric layouts or draping. Designers craft timeless, versatile garments with simple cuts and multifunctional designs to ensure durability and long-term use. Production is done in small batches using eco-friendly materials and dyes, reducing overproduction and waste. Leftover scraps are reused or upcycled, and consumers are encouraged to repair and maintain garments — supporting a sustainable, waste-free, and ethically responsible fashion system.

CONCLUSION

Floriculture-inspired fashion represents a holistic approach to eco-friendly design. It merges aesthetics with ethics, encouraging designers to emulate nature's cycles in garment creation. By integrating botanical elements, natural dyes, and regenerative systems, this movement advances the sustainability agenda in the fashion industry. Nevertheless, challenges persist, including the scalability of natural materials and consumer perception of cost. Overcoming these barriers will require continued innovation and education in sustainable design practices.

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INDIAN DESIGNERS REDEFINING FASHION WITH FOOD WASTE

Abstract

India's designers are pioneering a sustainable revolution by transforming food waste into eco-friendly fashion materials. From fruit peels to crop residues, organic waste once seen as worthless is now a resource for textile innovation. This article examines the motivations behind using food waste, its practical applications in fashion and textile production, and the product innovations emerging from this creative movement. The article concludes that the food-to-fashion movement exemplifies how creativity, environmental responsibility, and scientific inquiry can work together to address waste challenges.

Introduction

The global fashion industry is among the largest contributors to waste, producing over 92 million tonnes of discarded textiles annually (Business Waste, 2025). India, as both a fashion producer and consumer, faces similar challenges with mounting textile and household waste. According to national estimates, the country produces around 78 million tonnes of household waste each year, much of which is organic food waste (Times of India, 2025).

While these numbers reflect environmental pressure, they also reveal opportunity. A growing number of Indian designers are converting food waste — fruit skins, crop residues, and discarded peels — into innovative fabrics and accessories. This creative approach aligns with the principles of the circular economy, which emphasizes minimizing waste and maximizing resource use (Ellen MacArthur Foundation, 2021). The integration of food waste into fashion reflects a shift from linear to regenerative production models. This article explores why food waste is an important raw material, how it can be applied to textiles, and how Indian designers are translating this idea into tangible, market-ready products.

How Can It Be Transformed into Textile?

The transformation of food waste into fashion involves scientific innovation, design creativity, and sustainability principles. Several key applications have emerged across India's sustainable design community.

Natural Fiber from Banana Pseudo-stem Waste

Banana Pseudo-stem → Cleaning & Pre-treatment

↓

(Enzymatic or mild alkali retting loosens fibers)

↓

Mechanical Decortication → Fiber Extraction

↓

Washing & Neutralization → Drying → Carding

↓

Spinning → Weaving/Knitting

↓

Finishing (Natural softeners & dyes)

↓

→ Biodegradable yarns and fabrics for eco-textiles

2. Bio-Based and Composite Materials

Process

Bio-Based Composite from Coconut Water Waste

Discarded Coconut Water → Filtration & Sterilization

↓

Fermentation (using Acetobacter bacteria)

↓

Bacterial Cellulose Sheet Formation (7–14 days)

↓

Harvesting & Washing → Drying & Pressing

↓

Composite Formation (blended with natural fibers)

↓

Surface Finishing (wax or natural latex coating)

↓

→ Vegan leather-like biocomposite sheets

3. Natural Dye Extraction

Natural Dye from Pomegranate Peel Waste

Pomegranate Peels → Cleaning & Drying
↓
Grinding → Boiling in Water (Pigment Extraction)
↓
Filtration → Dye Solution
↓
Mordanting Fabric (with alum or iron)
↓
Immersion in Dye Bath → Rinsing & Shade Drying
↓
→ Naturally dyed textiles in yellow to brown tone

Indian Innovations

India has become a center of innovation in waste-based design. Notable examples include:

Malai Biomaterials (Kerala): Uses discarded coconut water to produce flexible, leather-like bio-composites.

Banofi Leather (Uttar Pradesh): Converts banana plant waste into vegan leather sheets for accessories and footwear.

Rimagined (Bengaluru): Focuses on upcycled fabrics and waste-derived home décor.

ALT Mat: Develops fibers from fruit waste using biotechnology for the fashion industry.

These initiatives showcase the intersection of creativity, science, and sustainability. Their success has positioned Indian designers at the forefront of global discussions on eco-fashion and material innovation.

Conclusion

Indian designers are pioneering a new era of sustainable fashion by transforming food waste into innovative materials that unite creativity with environmental responsibility. By repurposing fruit peels, crop residues, and organic by-products, they demonstrate how design can turn ecological challenges into opportunities for regeneration.

This movement reflects a cultural and scientific shift toward circular production — merging traditional craft with modern biotechnology. Each creation, from banana fiber textiles to coconut-based leather and natural dyes, embodies India's capacity to combine artistry with sustainability.

More than an aesthetic trend, this approach redefines the value of waste and supports the nation's journey toward a circular economy. By converting what was once discarded into meaningful fashion, Indian innovators are shaping a future where sustainability becomes both a creative and ethical cornerstone of design

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INTEGRATED FARMING SYSTEM: A PATHWAY TO PROSPERITY FOR SMALL AND MARGINAL FARMERS

Introduction:

In India, where nearly **85% of farmers** belong to the small and marginal category, improving livelihoods while ensuring sustainability has become a pressing need. Traditional farming methods often fail to provide adequate income due to small landholdings, unpredictable weather, and rising input costs. Amidst these challenges, the **Integrated Farming System (IFS)** has emerged as a ray of hope — a holistic approach that combines crops, livestock, fisheries, forestry, and other enterprises on the same farm to maximize productivity and income.

Krishi Vigyan Kendra (KVK), Bhadradri Kothagudem is successfully maintaining a **Non-Watershed Integrated Farming System (IFS)** model aimed at improving the livelihood security of small and marginal farmers in the region. The system integrates multiple farming components such as **crop production, horticulture, dairy, poultry, goat rearing, fishery, and vermicomposting** within a single farm unit to ensure efficient resource recycling and year-round income generation. By linking crop residues, livestock manure, and water resources in a complementary manner, the model demonstrates sustainable utilization of available farm resources even under rainfed conditions. This holistic approach not only enhances productivity and profitability but also strengthens farmers' resilience against climatic uncertainties while serving as a **live demonstration and training model** for the farming community.

What Is an Integrated Farming System?

The **Integrated Farming System (IFS)** is a sustainable model that integrates various agricultural components such as:

- **Crops** (cereals, pulses, vegetables, fruits)
- **Livestock** (cows, goats, poultry, pigs)
- **Fishery and duckery**
- **Agroforestry and horticulture**
- **Beekeeping, mushroom cultivation, vermicomposting**, and more

Each component supports the other — for example, crop residues feed livestock, livestock manure enriches the soil, and pond water nourishes the crops. This **recycling of resources** reduces costs and boosts productivity.

Why Is IFS Important for Small and Marginal Farmers?

1. **Efficient Use of Land and Resources**
   Small landholdings are fully utilized by integrating multiple components. Every part of the farm — field, pond, bund, or shed — contributes to income.

2. **Income Diversification and Risk Reduction**
   Dependence on a single crop is risky. If one enterprise fails due to drought or pests, others like dairy or poultry can support the family, ensuring financial stability.

3. **Employment Generation**
   Integrated systems create **year-round employment** for family members through crop care, livestock management, and value-added activities.

4. **Nutritional Security**
   Producing cereals, vegetables, milk, eggs, and fish on the same farm ensures a **balanced diet** for the farming household.

5. **Environmental Sustainability**
   IFS promotes **organic recycling**, reduces chemical fertilizer dependence, and enhances soil fertility — protecting both the environment and future productivity.

Successful IFS Models in India

- **Crop + Dairy + Vermicompost Model (2 acres)**
  Common in Tamil Nadu and Karnataka, this system integrates fodder crops with dairy animals and composting, reducing fertilizer costs by 30–40%.

- **Rice–Fish–Duck System (Eastern India)**
  Practiced in Assam, Odisha, and West Bengal, where ducks control pests and their droppings fertilize the pond, increasing fish yield by up to 25%.

- **Crop + Goat + Poultry + Kitchen Garden (1 acre)**
  Ideal for dry regions — this low-cost model ensures steady income and family nutrition even under water scarcity.

<u>The recommended IFS model</u>

A diversified IFS that balances short-term cash, annual crops and long-term orchard income, plus livestock/poultry/fish and on-farm composting:

- **Horticulture:** Mango orchard (1 ha; ~100 trees) + **banana** in 0.2 ha as high-turnover cash crop

- **Seasonal field crops:** Maize/pulse rotation on ~0.5–0.6 ha (seasonal cereals + pulses)

- **Fish pond:** Small Pond (backyard / farm pond, ~200 m^3) for fish + water storage

- **Livestock:** Goats (4 adult does) for regular sales/biomass; **backyard poultry** (10 birds) for eggs/meat

- **Soil & fertility:** On-farm **vermicompost** unit, crop residue recycling

- **Irrigation & energy:** Drip irrigation (for orchard + banana) + solar pump (where grid reliability is poor)

- **Value-add / minor enterprises:** Vermicompost sales, apiary (2–3 bee boxes) and vegetable strips for household nutrition & market

This mix fits Telangana's semi-arid conditions (drip irrigation reduces risk), spreads risk across enterprises, and gives both short-term and medium/long-term cash flows.

Key assumptions

Area = **1 hectare** (scale linearly).

- Mango orchard: **100 trees/ha** (planting + first reliable commercial crop from Year 3).

- Banana on **0.2 ha** gives quick cash every 9–12 months.
- Fish pond ~200 m^3 (small earthen / lined pond).
- Small goat unit (4 breeding does) and backyard poultry (10 birds).
- Prices, wages and input costs are approximate — please replace with exact local quotes.

One-time establishment costs — 1 hectare (INR)

Item	Cost (₹)
Land preparation, seeds/planting material for seasonal crops	20,000
Mango orchard (saplings, planting, staking)	30,000
Banana planting (0.2 ha)	60,000
Seasonal crops inputs (seed, fertilizer, chemicals)	25,000
Drip irrigation system (1 ha sized; laterals, filters)	75,000
Vermicompost unit (setup)	15,000
Backyard poultry setup (shelter, chicks, initial feed)	15,000
Goat unit (4 animals + shelter)	60,000
Fish pond excavation & lining + fingerlings, inputs	70,000
Solar pump (small)	40,000
Fencing, tools, shade net etc.	10,000
Total establishment cost	**₹420,000**

Total establishment = **₹4,20,000** (₹4.2 lakh). (You can reduce cost by delaying orchard planting, using contractor/tribal labour, or using community drip subsidies.)

Annual recurring costs (yearly maintenance & working capital)

Breakdown (approx.):

- Fertilizer, pesticides, seed, agronomy inputs: ₹30,000
- Labour (planting/harvest/maintenance): ₹50,000
- Livestock & fish feed, medicines: ₹40,000
- Irrigation electricity / system maintenance: ₹20,000
- Vermi inputs/consumables: ₹10,000
- Misc / contingency: ₹20,000

Total annual recurring cost = **₹1,70,000** (₹1.7 lakh)

Projected annual gross returns

Conservative estimates (year when mango orchard is producing well; typically Year 3+):

- Mango (100 trees × avg. 50 kg/tree × ₹40/kg) = ₹2,00,000 *(assumes 50 kg/tree; price varies by year & variety)*
- Banana (0.2 ha → ~8,000 kg × ₹12/kg) = ₹96,000
- Seasonal crops (maize/pulses rotation) = ₹80,000
- Livestock + poultry + fish combined (sales, eggs, fingerling sales) = ₹60,000
- Vermicompost & small value-add sales = ₹20,000

Total gross income (steady year) = **₹4,56,000** (₹4.56 lakh)

Net profit and basic economics

- Gross income = ₹4,56,000
- Recurring costs = ₹1,70,000
- **Net annual cash surplus** = **₹2,86,000**

Return relative to establishment:

- Establishment cost = ₹4,20,000
- Net annual = ₹2,86,000 → **return ≈ 68%** of establishment cost (net/establishment). If orchard is mature, **payback** on establishment ≈ **1.5 years** (after orchard reaches steady production).(These are estimates — orchard establishment years 1–2 will have lower returns.)

Year-by-year cash flow sketch (simplified)

- **Year 0–1 (establishment):** High investment (₹4.2L). Little to no orchard income; banana and seasonal crops provide some cash. Consider staggered planting or loan/subsidy to manage cashflow.
- **Year 2:** Banana and seasonal crops give steady income; mango begins to give small yields. Livestock/fish start contributing.
- **Year 3 onward:** Mango gives commercial yields; net income reaches projected steady state.

Practical operational plan (first 12 months)

1. **Month 1–2:** Land shaping, orchard pit digging, pond excavation, buy saplings, set up vermi unit.
2. **Month 3:** Plant mango + banana suckers; install drip system and solar pump.
3. **Month 4–6:** Plant short-term crops (maize/pulses) in available area; start poultry/goat purchase and shelters.
4. **Month 7–9:** Maintain drip & fertigation, start fish stocking in pond (if water ready), fertilize & manage crops.
5. **Month 10–12:** Harvest seasonal crops; sell produce; make vermicompost; prepare for next season. Keep records and plan marketing.

Risk management & good practices

- **Drip irrigation** is key in Telangana: reduces water stress and increases yield per drop. Seek local government drip subsidy.
- **Crop diversification** reduces price risk — pulses + maize + banana + mango.
- **Farmer groups / FPOs** help marketing and buy inputs cheaper.
- **Soil testing** before major inputs — apply balanced fertilizer.
- **Record keeping** of costs, yields and sales helps compute real profit and access credit.
- **Value addition** (mango pulp, banana chips, vermicompost sales) raises margins.

How to scale down (for marginal farmers)

- If you have **0.4 ha (1 acre)**, multiply the establishment and recurring numbers by **0.4**.
  Example: establishment ≈ ₹1.68 lakh, recurring ≈ ₹68,000, gross & net scale roughly the same proportionally.
- Another option: start with **only banana + seasonal crops + livestock/vermi** on 0.5 ha; plant mango later.

Quick summary table (1 ha)

Metric	₹
Establishment cost (one-time)	420,000
Annual recurring cost	170,000
Gross annual income (steady)	456,000
Net annual surplus	286,000

Economic and Social Impact

Studies by ICAR (Indian Council of Agricultural Research) have shown that integrated farms can **increase net income by 2 to 3 times** compared to monocropping. Moreover, farmers report **higher self-reliance**, improved food availability, and stronger community networks through shared knowledge and resources.

The Way Forward

To make IFS widespread, **training, financial support, and market linkages** are essential. Government schemes like the **National Mission for Sustainable Agriculture (NMSA)** and **Rashtriya Krishi Vikas Yojana (RKVY)** are already promoting integrated approaches. With proper guidance and adoption, IFS can transform rural livelihoods and make farming not just a way of life — but a **profitable and sustainable enterprise**.

Where to get help

Present this plan to your **KVK (Krishi Vigyan Kendra)** — they can help with saplings, training, demonstrations, and locally adapted varieties.

- Check for **state/national subsidies** for drip, solar pumps, fish pond, and orchard planting (apply through agriculture dept / horticulture dept).

- Consider **microcredit** / small bank loan for the establishment cost, showing projected cash flows above.

Conclusion

The Integrated Farming System is more than a technique — it is a **philosophy of harmony between nature and livelihood**. For small and marginal farmers, it offers a practical roadmap to double income, ensure food security, and build resilience against climate change. By embracing integration over isolation, the future of Indian agriculture can indeed be **green, sustainable, and prosperous**.

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INTEGRATING PERMACULTURE PRINCIPLES INTO FASHION PRODUCTION

Introduction

The global fashion industry is one of the most influential cultural forces, and one of the most resource-intensive. From water-heavy cotton farming to chemical dyes and synthetic fibres, fashion's environmental footprint is undeniable. Yet, amid rising awareness of climate change and sustainability, the question arises: Can fashion truly exist in harmony with nature?

One promising answer lies in permaculture, a system of ecological design based on the patterns and processes of natural ecosystems. While permaculture originally emerged as a method for sustainable agriculture, its principles can extend far beyond farming, into how we live, create, and even produce clothing. Integrating permaculture principles into fashion production opens the door to a more regenerative, ethical, and circular fashion future.

Understanding Permaculture

Permaculture, coined by Bill Mollison and David Holmgren in the 1970s, combines "permanent" and "agriculture," later expanding to "permanent culture." It's rooted in three core ethics:

1. Care for the Earth – protecting and regenerating natural systems.
2. Care for People – ensuring human needs are met in fair and just ways.
3. Fair Share (Return of Surplus) – redistributing excess to support the system as a whole.

These ethics are supported by twelve design principles, such as "Produce No Waste," "Use and Value Renewable Resources," and "Design from Patterns to Details" (Holmgren, 2002). When these ideas are applied to fashion, they encourage us to rethink the industry's linear "take–make–dispose" model and replace it with one that mimics the circular flow of nature.

As Greenly Earth (2024) notes, permaculture is not just about reducing harm, it is about creating systems that actively restore and regenerate the environment.

Applying Permaculture Principles to Fashion Production

1.Care for the Earth

This principle urges fashion to protect ecosystems through responsible material sourcing, energy use, and waste management. Organic and regenerative fibres, natural dyes, and biodegradable materials are key.

For instance, regenerative cotton farms focus on soil health, biodiversity, and carbon sequestration, aligning directly with the permaculture principle of "Use and Value Renewable Resources." Similarly, dyeing processes can shift from toxic synthetics to plant-based or microbial dyes, reducing water and soil contamination. Our Permaculture Life (2024) notes that sustainable fashion seeks to "protect soil, natural habitats, and biodiversity while increasing water efficiency." Even small steps, like composting fabric scraps or using rainwater in dyeing, help restore balance between fashion and the environment.

2.Care for People

Permaculture values community, cooperation, and fairness. In fashion, this means valuing human hands and stories behind garments. Ethical working conditions, fair wages, and local craftsmanship become central.

Brands inspired by permaculture often collaborate with local artisans, using traditional weaving or dyeing techniques that sustain both culture and livelihoods. This approach humanizes the production chain, replacing faceless mass production with relationships, care, and respect.

As Textile Beat (2024) highlights, garments made by people who are valued and respected hold a "depth and connection" that mass-produced items lack.

3.Fair Share / Redistribute Surplus

In natural ecosystems, nothing goes to waste. Every output becomes someone else's input. Fashion can adopt this mindset by developing circular systems, recycling, upcycling, and reusing materials rather than discarding them.

For example, leftover fabric scraps can be turned into patchwork collections, while old garments can be disassembled and remade. The principle "Produce No Waste" applies perfectly here. Fashion waste can also be composted when made from natural fibres, returning nutrients to the soil. According to Word Forest (2024), embracing this principle encourages industries to see "waste" as a resource, fostering creativity and efficiency at every stage of production.

Fashion and Nature: Rediscovering the Connection

Historically, fashion and nature were intertwined. Textiles came from plants and animals, cotton, wool, silk, flax, and colors came from natural dyes. However, industrialization replaced these organic systems with synthetic materials, chemical dyes, and exploitative production chains. This shift distanced fashion from its natural roots. Permaculture brings back that connection. It asks fashion creators to see garments not as disposable products but as part of a living cycle. This means designing clothing that begins and ends in harmony with nature, sourced responsibly, worn consciously, and returned safely to the earth or reimagined into something new.

A report by Textile Beat (2024) emphasizes this mindset, calling for a "slow clothing" approach that encourages consumers to "build, mend, and restore" rather than "buy, consume, and discard."

The future of fashion is fundamentally dependent on the health of our planet. The industry's shift is no longer a niche trend but a necessary evolution, driven by consumer demand and ecological imperative. By adopting regenerative practices, embracing circularity, and prioritizing radical transparency, fashion is not just mitigating its harm; it is transforming into a force that can actively contribute to the vitality of natural systems.

Designing Like Nature: Systems Thinking in Fashion

Nature does not create waste or pollution, it creates cycles. Every fallen leaf becomes soil; every organism plays a role in balance. If fashion were to mimic this system, it would focus on circularity, designing for longevity, repairability, and regeneration. A Possibility Project article (2024) calls for a cultural shift from the mindset of "consume/discard" to one of "build/mend/restore." This means designing clothes that can be taken apart, reused, or returned to the earth. Materials would be renewable, and production would rely on renewable energy sources.

Permaculture's principle of "Design from Patterns to Details" encourages designers to observe the bigger picture first, ecosystems, communities, lifestyles, before focusing on color or cut. This systemic awareness ensures fashion supports both planet and people.

The Future of Regenerative Fashion

Integrating permaculture into fashion is not a marketing gimmick; it is a paradigm shift. It redefines beauty and success not by profit margins, but by positive impact, on ecosystems, workers, and consumers alike.

A truly regenerative fashion industry could:

Support soil health and biodiversity through regenerative fibre farming.

Ensure fair trade and community- centred production.

Design garments for longevity, repair, and reuse.

Create closed-loop systems where nothing is wasted.

When fashion aligns with permaculture, it becomes more than style, it becomes stewardship. It is a reminder that the threads we wear are deeply connected to the threads of life itself.

How Permaculture Connects to Fashion Production

At first glance, permaculture and fashion might seem unrelated, one focuses on growing food and designing ecosystems, the other on fabrics and aesthetics. Yet, both share a deeper common goal: creating systems that sustain life. Permaculture is essentially a way of designing that works with nature, and when we apply that same thinking to fashion production, we begin to create clothing that supports people, the planet, and future generations.

1. From Farms to Fabrics

Permaculture begins with soil, caring for the earth that provides our raw materials. This directly connects to fashion's first step: fibre production.

Regenerative agriculture, a key practice inspired by permaculture, can be used to grow cotton, hemp, and flax in ways that restore biodiversity and soil health (Holmgren, 2002).

Instead of using harmful pesticides, farmers use natural composting and crop rotation to keep ecosystems healthy.

This approach mirrors the permaculture principle "Care for the Earth." In fashion, that means using regenerative or organic fibres to ensure that what we take from nature can replenish itself. According to Greenly Earth (2024), permaculture encourages "working with natural processes to reduce waste and preserve the health of ecosystems."

2. Designing with Nature's Logic

Permaculture design mimics natural cycles, where nothing is wasted, and every output feeds something else. Fashion production can adopt this circular logic by:

Turning off-cuts and wastes into new designs.

Using natural dyes that return safely to the environment.

Designing garments for durability, repair, and reuse rather than quick disposal.

This reflects Holmgren's (2002) principle "Produce No Waste." Textile Beat (2024) reinforces this idea through the concept of "slow clothing," which encourages consumers and makers to "build, mend, and restore" instead of constantly buying and discarding.

3. Respecting the Hands Behind the Clothes

One of permaculture's three ethics is "Care for People." Sustainability is not only about the planet; it is also about fairness, dignity, and human connection.

In fashion, this means:

Ensuring safe and fair working conditions for garment makers.

Supporting local communities and traditional artisans.

Valuing craftsmanship over mass production.

As Our Permaculture Life (Gamble, 2024) explains, sustainable fashion involves "respecting people's labour, valuing small-scale production, and reconnecting consumers with makers." When fashion production honours people as much as materials, it reflects the social harmony that permaculture seeks to cultivate.

4. Closing the Loop, No Waste

In nature, waste does not exist. Every leaf that falls feeds the soil. Similarly, fashion can follow this natural law through circular production:

- Recycling old textiles into new fabrics.
- Composting natural fibres at the end of their life.
- Reusing water and natural dye solutions in textile processing.

This aligns with the permaculture principle "Use and Value Renewable Resources" (Holmgren, 2002). The Word Forest Organisation (2024) describes it perfectly: "Permaculture systems are designed so that resources are renewed rather than depleted, an approach that can inspire every industry, including fashion."

Conclusion

Integrating permaculture principles into fashion production calls for deep reflection and radical creativity. It asks us to slow down, look closer, and understand that fashion does not exist apart from nature, it is nature. By caring for the earth, caring for people, and sharing resources fairly, the industry can evolve from exploitative to regenerative. Fashion, at its best, has always been a form of self-expression, now, it can also express care, consciousness, and coexistence. As designer and permaculture advocate Morag Gamble (2024) says, "The most sustainable garment is the one that connects you, to the earth, to people, and to purpose."

When we integrate permaculture into fashion, we do not just change how clothes are made; we transform what fashion means.

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Mini Clonal Technology: A Revolutionary Approach for Quality Planting Material Production

Abstract

Quality Planting Material (QPM) is the backbone of modern forestry and agroforestry systems, ensuring higher productivity, uniformity, and resistance to biotic–abiotic stresses. Traditional vegetative propagation methods such as conventional cuttings, macro-cloning, and nursery raising have limitations like low multiplication rates, poor rooting, and higher space requirements. **Mini Clonal Technology (MCT)**, pioneered by the WIMCO and ITC forestry programmes, has emerged as a breakthrough method to mass-produce elite clones of tree species with superior genetic potential.

Introduction

The success of any plantation programme largely depends on the availability of healthy, fast-growing, and genetically superior planting stock (**Arunachalam *et al.*,2024**) Traditionally, seedlings produced through seeds have been the main source of planting material for forestry and agroforestry species. However, seed-based propagation often results in large variability in growth, yield, and form because of genetic heterogeneity. In recent decades, **clonal forestry** has emerged as a transformative solution to produce uniform and high-yielding planting material. **Mini Clonal Technology (MCT)** is a refinement of conventional clonal propagation methods. It allows mass multiplication of improved clones in a **cost-effective, space-efficient, and environmentally controlled** manner. This technology has been successfully adopted in several tropical tree species such as *Eucalyptus*, *Casuarina*, *Melia dubia*, *Acacia*, and *Poplar* (**Parthiban *et al.*,2021).**

What is Mini Clonal Technology?

- Under this technology, the superior clonal plants are planted in a mini clonal garden and are provided with regular irrigation and fertilization in order to enhance shoot multiplication.

Key Features

- Uses **small hedge plants (20–40 cm height)** instead of big mother plants.
- Produces **juvenile, softwood shoots** with excellent cloning efficiency.
- Designed for **rapid, large-scale, cost-effective** QPM production.

Components of Mini Clonal Technology

Mini-Hedge Garden

- Established using **clonally selected elite mother plants**.
- Spacing: 10 × 10 cm, 15 × 15 cm (species-specific).
- Irrigation: Drip/micro-sprinklers.
- Nutrition: Regular fertigation with balanced NPK.

Mini-Cuttings

- Softwood mini-cuttings (2–4 cm) harvested every **7–15 days**.
- High vigour due to continuous rejuvenation of mini-hedges.
- Requires minimal wounding and hormone dosage.

Rooting Environment

- Rooting in **mist chambers**, low-pressure foggers, or poly-houses.
- Ideal conditions:
  - Humidity: **80–90%**
  - Temperature: **22–28°C**
  - Light: Diffused

Hardening and Nursery Management

- Rooted cuttings shifted to **polybags or root-trainers**.
- Gradual exposure to outside environment.
- Ready for field planting within **60–75 days**.

Steps in Mini Clonal Technology

- **Selection of Superior Clones**
- Establishment of Mini Clonal Garden (MCG)
- Production of Mini Cuttings
- Rooting of Mini Cuttings
- Hardening and Nursery Management
- Field Planting

Advantages of Mini Clonal Technology

- **High Multiplication Rate**: Continuous shoot production enables year-round propagation.
- **Space Efficient**: Requires only a fraction of the land compared to conventional clonal gardens.
- **Cost-Effective**: Lower maintenance and input costs per plant.
- **Genetic Uniformity**: Ensures plantations are established with improved, true-to-type material.
- **Better Quality Plants**: Rooted cuttings show higher survival and faster early growth in the field.
- **Reduced Disease Incidence**: Nursery environment can be better controlled.

Applications in Forestry and Agroforestry

Mini clonal technology has been adopted widely in commercial forestry programmes in India and abroad. Public and private sector organizations have used this technology to mass-produce high-yielding clones of *Eucalyptus* and *Casuarina* for pulpwood plantations. Similarly, *Melia dubia* and *Acacia auriculiformis* are being propagated for timber and agroforestry systems (**Parthiban *et al*., 2024**) This technology is especially useful for **farmer-oriented plantation programmes**, where reliable planting material is essential for ensuring profitability and sustainability.

Species Suitable for Mini Clonal Technology

Highly Successful

- Eucalyptus spp.
- Populus deltoides
- Casuarina equisetifolia
- Melia dubia
- Gmelina arborea

Moderately Successful

- Leucaena leucocephala
- Dalbergia sissoo
- Acacia hybrids

Challenges and Considerations

- **Initial infrastructure costs** (e.g., mist chambers, shade houses) can be significant.
- **Regular technical supervision** is needed to maintain clone identity and plant health.
- Some **species may require optimization** of rooting protocols.

However, once established, mini clonal technology offers **a sustainable and scalable system** for producing millions of quality plants annually.

Conclusion

Mini Clonal Technology represents a **scientific, efficient, and farmer-friendly** approach for large-scale production of quality planting material. By integrating improved genetic material with innovative nursery practices, this technology has the potential to **enhance productivity, uniformity, and profitability** in forestry and agroforestry plantations. Wider adoption and capacity building at the state and community levels can make this technology a game changer in tree farming initiatives.

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Upcycling agricultural by-products into fashion accessories (using husk, shells and stalks to make jewelry, handbags and footwear)

ABSTRACT
Upcycling agricultural by-products into fashion accessories presents an innovative approach to sustainable design and waste management. This paper explores the potential of materials such as husks, shells, and stalks to be transformed into eco-friendly products including jewelry, handbags, and footwear. Upcycling, or creative reuse, converts agricultural residues that are typically discarded such as rice husks, coconut shells, and banana fibers into high-value materials with artistic and functional appeal. The study discusses the characteristics of these materials, the upcycling process, and their application in the fashion industry. Beyond aesthetic and functional value, this practice offers significant environmental and socio-economic benefits, including waste reduction, resource conservation, biodegradability, and rural employment generation. By linking agriculture, craftsmanship, and fashion, upcycling fosters a circular economy and promotes sustainable consumer behavior. Ultimately, transforming farm residues into fashionable products redefines waste as a resource and highlights fashion's role in environmental stewardship and creative innovation.
Keywords: upcycling, sustainable fashion, agricultural by-products, eco-design, circular economy, environmental innovation

INTRODUCTION-

Our fundamental value is upcycling. Upcycling, often referred to as creative reuse, is the process of repurposing leftovers, waste products, unnecessary items, or unwanted items to make new materials or items that are thought to be of higher quality, such as items with artistic and environmental value. In a word, it is a process for turning waste materials into goods of the same quality or better. This is a reference to the inventive recycling of worn textiles in the fashion industry. But we frequently use natural resources, transform them into valuable items, and then eventually discard them as trash. Upcycling can be defined as the process of taking something that is throwaway and turning it into something more valuable. Therefore, upcycling involves improving upon what is currently available. (Anonymous. 2025)

Upcycling agricultural by-products like husk, shells, and stalks into fashion accessories is a sustainable practice that creates value from waste. Examples include jewelry made from coconut shells and seeds, handbags crafted from coconut husks, and footwear incorporating various crop residues and stems. This approach reduces environmental pollution, plastic use, and resource wastage while creating economic opportunities for farmers and local communities. (Vigneswaran, C., & Selva, P. S.)

This article explores how agricultural residues like **husk, shells, and stalks** can be effectively transformed into fashion accessories such as **jewelry, handbags, and footwear**. It highlights the materials, processes, design possibilities, and benefits of this innovative trend that bridges agriculture, craft, and sustainable fashion.

MATERIALS AND THEIR FASHION POTENTIAL

a. Husk-based Materials

Rice husks and coconut husks can be mixed with **bio-resins** or natural binders to create lightweight yet strong composites. These can be molded into shapes for handbags, buttons, soles, or jewelry components. The surface of rice husk composites provides a natural speckled appearance, adding aesthetic value.

https://tinyurl.com/coconut-husks

b. Shell-based Materials

Shells such as coconut, walnut, and betel nut shells are durable and naturally textured. When polished, they reveal beautiful brown tones that resemble wooden finishes. Artisans use these shells to make earrings, bangles, pendants, and bag embellishments. Coconut shells can also be ground and mixed with natural glue to form decorative panels for handbags or sandal straps.

c. Stalk-based and Fiber Materials

Plant stalks such as corn, wheat, or banana stems are sources of natural fibers. These fibers can be extracted and woven into fabrics that are biodegradable, breathable, and strong. For example, **banana fiber** is now widely used in eco-friendly handbags and footwear linings due to its strength and silk-like luster. Similarly, **jute and corn stalk fibers** can be used for soles, uppers, or woven handbag panels. (Gowda, T. M., & Rajput, B. S.)

THE UPCYCLING PROCESS

Upcycling agricultural by-products into fashion accessories involves several stages:

1. **Collection and Sorting:** Agricultural residues are collected from farms and processing units. Sorting ensures uniformity of size and quality.
2. **Cleaning and Drying:** Materials are thoroughly cleaned to remove impurities, then sun-dried or air-dried to prevent fungal growth.
3. **Processing and Treatment:**
    - Fibers are extracted through mechanical or manual methods.
    - Shells and husks are treated with natural oils or plant-based resins to improve durability and water resistance.
    - In some cases, natural dyes made from leaves, roots, or bark are applied to enhance color and finish.
4. **Design and Crafting:** Designers collaborate with artisans to develop innovative forms and patterns. Techniques such as weaving, carving, polishing, and molding are applied depending on the material.
5. **Finishing and Assembly:** Components are assembled into final products — jewelry, handbags, or footwear — using eco-friendly adhesives and fasteners. Each product is often handmade, emphasizing craftsmanship and uniqueness. (Karthik, T., & Rathinamoorthy, R).

APPLICATION IN FASHION ACCESSORIES

Jewelry

Coconut shells, rice husk resin beads, and seed shells are ideal for creating lightweight, organic jewelry. These materials are carved, polished, and sometimes combined with metal or textile elements to form modern yet earthy designs. Their natural colors eliminate the need for synthetic paints or dyes.

Handbags

Fibers from banana, corn stalk, or jute are woven or braided into panels that are then shaped into handbags. Designers often blend traditional weaving techniques with contemporary styles. The addition of shell or husk-based embellishments gives each bag a distinctive, eco-chic look.

Footwear

Upcycled footwear incorporates rice husk or coconut husk composites for soles, and banana fiber or jute fabrics for uppers. These shoes are breathable, lightweight, and biodegradable. Many eco-fashion startups are experimenting with natural latex and starch-based glues to ensure complete sustainability.

ENVIRONMENTAL AND ECONOMIC BENEFITS

The upcycling of agricultural by-products provides multiple benefits to the environment and society:

- **Waste Reduction:** Prevents the open burning of residues, which releases carbon emissions and causes air pollution.
- **Resource Conservation:** Reduces dependency on petroleum-based plastics, synthetic fabrics, and animal leather.
- **Biodegradability:** The resulting products naturally decompose, minimizing landfill waste.
- **Rural Employment:** Provides new income opportunities for farmers, artisans, and women's cooperatives.
- **Economic Value:** Turns low-cost waste into high-value designer goods.
- **Consumer Awareness:** Encourages sustainable consumption patterns among fashion

Conclusion

Upcycling agricultural by-products into fashion accessories represents a meaningful step toward a sustainable future. By using materials such as **husks, shells, and stalks**, designers are redefining fashion as an agent of environmental responsibility and cultural expression. These products not only reduce waste but also tell a story — a story of transformation from farm residue to fashionable art.

As consumers become more eco-conscious, the demand for such products is likely to grow. The movement encourages collaboration between farmers, artisans, and designers, creating a circular economy that values creativity and care for the planet. Ultimately, upcycled fashion accessories made from agricultural by-products are more than just style statements — they are symbols of innovation, resilience, and harmony with nature.

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Success story a transition from Shifting Cultivation to Broiler Production: A Sustainable Alternative for Livelihood and Environment

Abstract

Shifting cultivation (*jhum*) has been the dominant form of agriculture in hilly regions of Northeast India specially in Arunachal Pradesh. However, with increasing population pressure and reduced fallow cycles, its environmental and economic sustainability has come into question. This paper presents the case of Mr. Noklam Tingkhatra from Longding district, Arunachal Pradesh, who transitioned from traditional jhum farming to scientific broiler production. The article highlights the environmental impacts of shifting cultivation and discusses the economic and ecological importance of poultry farming as a sustainable livelihood alternative.

Introduction

For centuries, shifting cultivation has been a traditional agricultural practice among tribal communities in Northeast India. While initially sustainable due to long cycles of cultivation and fallow, in recent decades the practice has resulted in ecological degradation and low agricultural productivity. Declining soil fertility, deforestation, and uncertain yields have contributed to rural poverty and food insecurity.

In this context, diversification into scientific livestock production, particularly broiler farming, offers a promising alternative. Broiler production ensures quick returns, requires limited land, and provides both economic and nutritional security. The case of Mr. Noklam Tingkhatra illustrates this transition and its broader implications for sustainable farming systems.

Effects of Shifting Cultivation on the Environment

1. **Deforestation and Habitat Loss** – Large tracts of forest land are cleared annually for jhum cultivation, leading to biodiversity loss and habitat destruction.
2. **Soil Degradation** – Burning of vegetation and continuous cropping without sufficient fallow results in severe nutrient depletion and soil erosion.
3. **Climate Impact** – Slash-and-burn techniques release greenhouse gases, contributing to climate change.
4. **Hydrological Consequences** – Removal of vegetation reduces groundwater recharge, affecting water availability in upland villages.
5. **Declining Livelihood Viability** – With shortened fallow cycles, crop yields decline, making farming families vulnerable to poverty and food insecurity.

Importance of Shifting Towards Broiler Production

1. **Land Use Efficiency** – Requires minimal space compared to jhum.
2. **Economic Benefits** – Provides quick returns with high demand in local markets.
3. **Environmental Sustainability** – Poultry manure can be recycled as organic fertilizer.
4. **Employment Generation** – Involves family labor and creates opportunities for rural youth and women.
5. **Nutritional Security** – Poultry meat provides affordable protein.
6. **Integration with Other Farming Systems** – Can be combined with piggery, fishery, or horticulture.

Case Example: Mr. Noklam Tingkhatra – From Jhum to Broiler Farming

Mr. Noklam Tingkhatra, a progressive farmer from Longnaksi village under Kanubari circle of Longding district, Arunachal Pradesh, is a shining example of how scientific training and determination can bring about positive transformation in rural livelihoods.

In 2021, he attended a **7-day vocational training on poultry farming** at Krishi Vigyan Kendra (KVK), Longding. Despite acquiring technical knowledge, he did not immediately shift to poultry farming and instead continued practicing traditional *jhum* cultivation for a few more years. However, the declining productivity of shifting cultivation and the unstable returns from it gradually prompted him to revisit the training. Finally, in February 2025, he decided to shift his focus entirely towards scientific broiler farming.

To initiate his venture, he constructed a **low-cost raised bed poultry shed** measuring about 300 sq. ft., using bamboo and *toko pat* leaves for roofing. In May 2025, he began with **50 broiler chicks** on a trial basis. Over a 45-day cycle, the chicks consumed about **200 kg of feed** and attained weights of **2.0–2.8 kg**. Sold at ₹140 per kilogram, the batch earned him a **net profit of ₹8,600**.

Encouraged by this early success, he expanded to **100 chicks per batch** and adopted a **staggered rearing system**, ensuring a continuous supply of market-ready broilers. At present, his enterprise generates an **average monthly income of ₹24,000**, providing stability to his family. Strict adherence to **scientific management**, including regular vaccination and technical support from KVK-Longding, has been a key factor in his success. Notably, this year he has **completely given up jhum cultivation** and dedicated himself fully to poultry farming. This shift is both economically rewarding and environmentally significant, reducing deforestation and ecological damage.

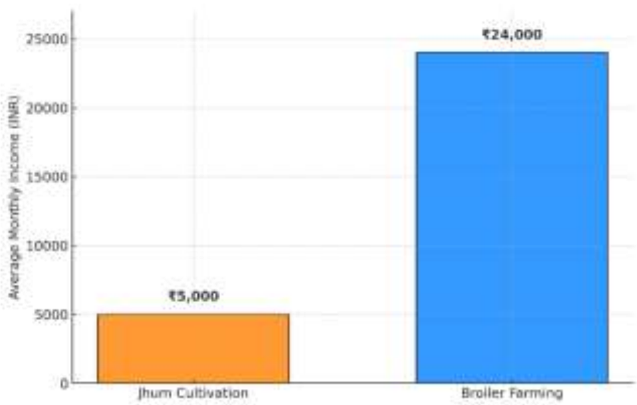

Figure 1. Income Comparison: Jhum Cultivation vs. Broiler Farming

Comparative Analysis: Jhum Cultivation vs. Broiler Farming

Parameter	Jhum Cultivation	Broiler Farming
Land Requirement	Large areas (1–2 hectares annually)	Very little land (300 sq. ft. shed for 100 birds)
Environmental Impact	Deforestation, erosion, biodiversity loss	Eco-friendly; manure improves soil
Production Cycle	Seasonal; one harvest per year	6–8 weeks per batch; multiple cycles
Yield/Returns	Declining yields, uncertain income	High and stable income; ready in 45 days
Average Income	Low, variable	Approx. ₹24,000/month
Labor Requirement	High manual labor	Moderate; family labor sufficient
Nutritional Value	Limited to seasonal crops	Rich source of protein and nutrients
Sustainability	Environmentally degrading	Sustainable, scalable, integrative

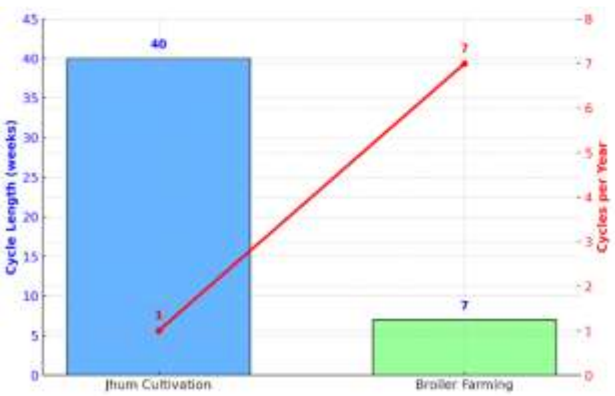

Figure 2. Production Cycle Comparison: Jhum cultivation vs. Broiler Farming

1. **Income Comparison Chart** – showing that average monthly income from broiler farming (~₹24,000) is far higher than from jhum cultivation (~₹5,000).
2. **Production Cycle Comparison Chart** – showing jhum has one long seasonal cycle (~40 weeks) while broilers have short cycles (~7 weeks) with up to 7 cycles per year.

Conclusion

The case of Mr. Tingkhatra demonstrates that with proper training, technical support, and determination, farmers can transition from environmentally degrading practices to sustainable and profitable enterprises. His journey serves as an inspiring model for other farmers in the region, showing how scientific broiler farming can effectively replace shifting cultivation as a source of livelihood and ecological security.

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ROLE OF INSECT TRAPS IN AGRICULTURE

Introduction

Insect traps have become indispensable components in contemporary agricultural practices, serving as vital instruments for pest management and control. Their primary function is to monitor, regulate, and diminish insect populations that causes damage the crops and in turn effecting the yield.

Functions and Benefits of Insect Traps

- Monitoring Pest Populations:
- Insect traps employ various attractants and capture mechanisms to collect insects, thereby providing farmers with crucial data regarding the presence and levels of pest populations in their fields.
- The no of insects trapped in the traps enables farmers to go for pest control measures, ensuring interventions are both timely and effective
- Early Detection of Pest Outbreaks: By identifying increases in pest populations early, insect traps allow for prompt action, which helps minimise crop loss eventually reducing cost of cultivation.
- Integrated Pest Management (IPM): When incorporated into an Integrated Pest Management (IPM) , insect traps complement and enhance the efficacy of biological, cultural, and chemical control methods. This approach supports sustainable agriculture by safeguarding both the environment and crop yields, making insect traps essential for long-term farm productivity.

Types of Insect Traps for Agriculture

In the realm of pest management, **sticky traps** have emerged as indispensable tools for monitoring and controlling insect populations in agriculture. Among the various types available, those with yellow, blue, and have gained prominence for their specific advantages in targeting different pests.

- **Yellow Sticky Traps: Yellow sticky traps** are among the most widely recognised and utilised tools in agriculture. Their bright yellow hue is highly effective at attracting a wide range of flying insects, including aphids, whiteflies, thrips. By naturally drawing these pests to their adhesive surface, the traps efficiently immobilise them, thereby preventing further damage to crops.

Advantages of Yellow Sticky Traps: Early detection of pests by regularly monitoring **yellow sticky traps,** farmers can detect pest infestations at an early stage, allowing for timely intervention before crossing the economic thresh hold limit. Early detection is key to implementing effective pest management strategies and preventing economic losses.

Blue Sticky Traps: Blue sticky traps are effective in targeting specific pests, such as thrips and leaf miners. The colour blue is highly attractive to these insects, drawing them to the sticky surface where they are captured and unable to cause further damage to crops.

Advantages of Blue Sticky Traps:

Thrips and leaf miners are common pests in many agricultural crops, causing damage through feeding and oviposition. Blue sticky traps offer a targeted solution for monitoring and controlling these pests, helping to prevent yield losses and maintain crop quality.

Reduced Need for Chemicals: By using blue sticky trats to monitor and suppress thrips and leafminer populations, farmers can reduce dependency on chemical pesticides, thereby minimizing, cost of cultivation , environmental impact.

White Sticky Traps: White sticky traps are less common but offer unique advantages in certain agricultural practices. While not as attractive to flying insects as yellow or blue traps, white traps are highly reflective and serve as effective barriers against crawling pests such as aphids, mites, and crawling insects.

Advantages of White Sticky Traps:

White sticky traps provide a physical barrier that prevents crawling pests from reaching the plant canopy, where they can cause damage through feeding and transmission of diseases. By intercepting pests before they reach the crop, white traps help reduce infestations and maintain plant health.

Pheromone traps: Pheromones are highly specific, non-toxic signaling molecules that facilitate communication between conspecifics, particularly in mating, aggregation, and alarm

signaling (Karlson and Lüscher, 1959).
In pheromone trapping, synthetic versions of these pheromones are used to mimic the communication signals of pests. There are different types of pheromones utilized in trapping, depending on the target pest species and the desired outcome. For example, sex pheromones, which are specific to mating, are commonly used to attract male insects to the traps. Aggregation pheromones, on the other hand, attract both male and female insects and are used to capture pests that tend to aggregate in specific areas.

Funnel Traps: Designed for pests with active flight and strong attraction to vertical visual cues, funnel traps are typically used for bark beetles (Scolytinae) and weevils (Curculionidae). These traps feature a series of interlocking funnels or vanes that guide the insect into a collection chamber, often fitted with an insecticidal strip or a drowning fluid to prevent escape.

Bucket traps consist of a lid containing the cage that holds the lure above a funnel leading to a holding bucket. The bucket trap is suspected by a wire hanger. The target insect is attracted to the lure, falls through the funnel and into the bucket, where an insecticide prevents escapes and minimises damage.

Delta traps are tri-folded to create a sheltered triangular area open at each end with a sticky side. They are available as single use, or with a replaceable sticky sheet.

Traps, unlike in-field sampling, continue to work 24/7. The primary advantage of pheromone traps is they have minimal bycatch compared to other attractant or incidental trapping methods, allowing a faster assessment of target pest numbers.

Fruit fly trap: Methyl eugenol trap is useful for trapping the male fruit fly. Bactrocera zonata, B. dorsalis, B. correctus and B. diversa. It is to installed in orchard @ 5 traps/ha at 1.5m height from the ground level. Periodically trapped flies should be collected and recharge the methyl eugenol soaked foam every 7-10 days interval. Such tool is very effective to manage the infestation of to fruit fly in orchards if installed on a mass campaign base. One or two trap in a orchard is useful for monitoring purpose.

Probe trap: Probe trap is used to detect pests within the bulk of grain storage. Probe trap is more effective as compared to detect pests with taking grain samples. The trap should be placed in a pair into the grain at approximately 4-6 meters apart. One trap placed so that the holes are level with the surface of the grain and one buried up to 10cm below the grain surface.

With the advent of technology and recent surge in the insect population , the eco-friendly and natural approaches are helpful in pest management on agricultural crops. These approaches enable the farmers to carry out sustainable cropping and avoid use of harmful insecticides.

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EFFECTS OF CLIMATE CHANGE ON AGRICULTURE IN INDIA

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Introduction:

The agricultural sector of India is not only an important element of the state economy; it is the bread-winner of millions of people. It consumes about 16 to 18 per-cent of the GDP and it employs nearly 50 per-cent of the labor force. On the dry deserts of Rajasthan to the lush plains of Punjab, farmers cultivate a wide range of food such as rice, wheat and sugarcane. But now climate change becomes a significant threat. Extreme events, more frequent and increase in temperatures, are putting farmers in difficult situations. The threats are not limited to losing crops; food security is under threat and the smallholders who are already in a vulnerable situation are even more challenging. Climate change, which is being globalized by the anthropogenic emission of greenhouse gases, is already impacting India farm production. Scientists warn that unless significant measures are undertaken the crop yields might drop drastically in the next few years. This may cause food shortages, food increase in prices and India having to import more food. Key impacts of climate change in Indian agriculture encompass the effects it has in terms of crop and water supply, soil and economy.

Crop and Production:

There have been effects on crops and production. A reduction in crop growth due to changes in crop growth rates is one of the most direct ways that climate change damages Indian agriculture. An increase in temperature may lead to crops growing too fast leaving them a reduced time to accumulate grains. Wheat and rice are the crops that are vulnerable to heat especially. To illustrate, crop production of wheat in India has decreased drastically in the country since 2001, as temperatures exceeding 34°C are debilitating. Farmers have shifted to suit some crops such as rice and maize but wheat is still under a high risk. The extreme weather has also been experienced in almost all India regions and has intensified a lot. Extremes like heat waves, floods and droughts are now familiar occurrences. In March 2022 severe heatwave with small amounts of precipitation led to 10-35 per-cent reduction in crop yields in affected regions. The other memorable episode happened in 2005 in Ludhiana, with temperatures remaining over 42°C over a period of 13 days resulting in reduction of wheat production to 28 per-cent.

It is not isolated cases but harbingers of a great danger to agriculture. Association of scientists cautions that the increase in the global warming temperature will reduce the world production of wheat by 6-10 per-cent. The corresponding effects of particular crops are also evident. China Rice is the key crop and a large export of India and it is very much susceptible to unpredictable monsoons. The sick and production yields of rainfed rice may reduce by approximately 47 per-cent by the year 2080, without any new way of farming. The reduction in wheat would be 40 per-cent and that of maize 23 per-cent in the same period. The content of nutrients will also reduce, and this will contribute to food insecurity. The 2015-2021 flooding and droughts destroyed more than 68 million hectares of annual crops in demonstration of the twin menaces, the excess and the shortage.

Water and Irrigation:

Indian agriculture relies heavily on water, and more than 60 per-cent of farmers utilize rain and groundwater to irrigate their farms. Climate change aggravates the water crisis by causing the change in rainfall, glacier melting as well as increasing the rate of evaporation. Glaciers on the Himalayas that nourish huge rivers like the Ganga are melting at an accelerated rate. Even though this would boost water flow at least temporarily, in the long run it will lead to less water and pose irrigation threats to the millions. The monsoon which is essential to farmers becomes more erratic on a daily basis. Warmer years become drier, colder ones get colder, which spurs more serious and frequent droughts and floods. By the turn of the millennium, the extremely wet monsoons which had been almost absent a hundred years before may happen every ten years. Northwest Indian droughts will increase. Already under pressure because of its rate of depletion, ground water will come under more pressure, with farmers pumping more water just to keep livestock alive. The heatwave also exacerbates the matter, which spurs a water rationing scenario, which was the case of 2024 as the temperature hit a high of 45°C.

Impacts on Soil Health and the Economy:

Climate change causes direct damage of soil. Floods wash away fertile top soil and droughts crack soil and bear away the vital nutrients. Whereas in areas like the coast, elevated sea levels and storms creep into the soil causing all the farmland to be useless. Increased temperatures contribute to growth of more pests and disease that result in additional damage to crops and soil. The financial impact is enormous. Overall, the investments of farmers lost $159.7 billion in 2021 due to extreme weather events, and the field of agriculture faced the greatest influence. In 2023 it was estimated that heat in 2022 cost 191 billion labor hours, or to lost income 219 billion. This can tally up to pertaining to the loss of 34 million full-time employment by 2030. Smallholders bear the brunt. As production of farms can be reduced by up to 53 per-cent and non-farm by 33 per-cent even by a small increase in temperature, there is an increasing disparity between the rich and the poor in agriculture. Poor households on average are losing 5 per-cent of their income on yearly heat stress and 4.5 per-cent on yearly floods. Food supply too is endangered as well, the food supply to India will have to raise beyond the current food also draw up to the year 2050. On the social side, the crisis causes certain people to leave, as climate refugees, leaving their houses in the search of new ways of living.

A Call to Action:

Nowadays, the study is rather clear that intervention does not auger well in the future. We large reductions in crop values, including to reveal 40 per-cent by 2080 of rice and wheat respectively. However, there is hope as far as we get on board with adaptation and mitigation. There are already pushbacks by some farmers; new and smarter seed varieties and new and smarter methods of farming. The government has introduced schemes already yielding more than 1,800 types of sustainability sourced quadruple crops and working on technology to address local issues. In order to really prepare, India must invest seriously in a more resilient agricultural system. This involves planting of drought residents, converting irrigation to efficient irrigation system, and maintaining soil life by agroforestry, organic farming, etc.

We also need well established early alert systems, crop insurance and means of providing the farmers with alternative forms of income. At the bigger level, the policies must take care of the least fortunate groups of people and expand social protection. By reducing its agricultural emissions, India has a chance to contribute to the world climate change fight. In brief, a climate transition is genuinely a crisis to Indian agriculture-in terms of production, water, economy, and equity.

Although the figures are frightening, an active strategy involving smart technologies and effective policy can help to safeguard millions of jobs and ensure food security travels the right path of agriculture.

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Menace in the Leaves: A Closer Look at the Secret World of Vegetable Mite Infestations

Abstract

Vegetable crops play a vital role in sustaining global food security, providing essential nutrients and dietary diversity to millions of people worldwide. However, the health and productivity of these crops can be significantly challenged by various pests, including mites. Mites are tiny arthropods belonging to the class Arachnida, and while some species are harmless, others can wreak havoc on vegetable crops, causing economic losses and reducing yields. Understanding the dynamics of mite infestations in vegetable crops and implementing effective management strategies are crucial for farmers and agricultural stakeholders. These phytophagous mites cause biotic stress to their host plant and negatively affect the marketable produce, costing growers money. Integrated mite management, which includes cultural control, the use of mite and insect predators, botanicals/biopesticides, and the management of fungi, bacteria, and viruses, is one environmentally friendly strategy that can be used to keep these mites under control in a variety of vegetable crops.

Introduction

The word mite is derived from Greek word Acari, and originated as early as 1650, but its existence was referred to 850 B.C. by Homer. Mites are arthropod animals belonging to sub class Acarina and class Arachnida, having no compound eye. They are small creatures and rich in diversity.

The mites have become major pests due to adoption of improved agronomic practices and use of modern insecticides which easily kill the insect predators of mites but without affecting the mites themselves. As a result mite species which were never seen earlier have come to be important pests.

Mites in vegetables are a common concern for farmers and gardeners alike. Additionally, mite infestations can render vegetables unmarketable due to physical damage and aesthetic concerns, leading to significant economic losses for growers. These tiny arthropods, often invisible to the naked eye, can cause significant damage to vegetable crops, leading to reduced yields and quality. With their very distinct physical makeup and eating habits, these tiny members are more similar to spiders and ticks than to any other insects, which typically have eight legs and lack both antennae and body segments. The typical method of feeding for many phytophagous mites is to stab their mouthparts into their host plants and sucking out the sap.

Some mites harm plants by producing web-like structures; curled leaves; speckled foliage; mottled leaves; and little dots (stippling) on the tissue of the leaves. Other mites produce growth deformities like galls. Puncturing and feeding plants may result in a deterioration in their health, sporadic leaf loss, and very infrequently, plant death. Among the various types of mites that infest vegetables, spider mites are particularly notable. The phytophagous mites belong to four families viz Tetranychidae (common red spider mite), Tenupalpidae (false spider mite),Tarsonemidae (yellow mite) and Eriophyidae (Eriophyid mite).

Mites infestations can have devastating consequences on vegetable crops. Beyond direct feeding damage, which can weaken plants and reduce photosynthetic capacity, mites also serve as vectors for various plant diseases. Their saliva contains enzymes that can facilitate the transmission of viral and bacterial pathogens, further compromising crop health.

Feeding Habit of Mites

Most of the plant mites are non-phototrophic and are normally found on the under surface of leaf either in colonies or in solitary forms. When the population on lower surface increases considerably, some of the mites may stray on to upper surface of the leaf and other parts of the plant like stem, petioles, fruits, buds etc. However, there are a few species which usually inhabit the upper surface of leaves (e.g. *Eutetranychus orientalis*, which infect citrus). Mites usually inhabit tender parts of plants like young leaves and shoots. A large number of mites may be found in the flowers, fruits and some mites are found within the galls. Phytophagous mites while feeding on plants penetrate the plant tissue by their needle like chelicerae and suck the sap. During the process of feeding, the mite extracts the chlorophyll resulting in white speaks on majority of host plants. There speaks enlarge gradually and coalesce to form big silvery spots. The chlorophyll loss due to feeding may be to an extent of 15 to 35% and this result in drying and dropping of leaves. Sometimes feeding also inject certain toxins during feeding which causes diverse reaction like retardation of growth, reduction in size of leaf, flowers and fruits, appearance of various types of plant deformities.

Life Cycle

Mites reproduce sexually as well as asexually. Fertilization results in the production of both female and male progeny, whereas parthenogenetic eggs develop into males in most species, but in certain species (e.g. *Brevipalpus phoenicis*) unfertilized eggs produce female progeny. Mating is generally accomplished immediately after the female emerges. Most of the plant feeding mites completes their life cycle in about a fortnight.

The life cycle of a tetranychid mite consists of an egg, three nymphal and an adult stage. The nymphal stages are called the protonymph, deutonymph and tritonymph. The protonymph also called as larva, has only three pairs of legs. But for this absence of posterior pair of legs and for the absence of genital openings, they, in most cases, resemble the adults. The eriophyid mite has only two nymphal instars which are not very different from the adult.

Egg : Mites lay their eggs singly, up to 100 per female, during her 3 to 4 week life span. The eggs are minute, spherical, translucent white to yellow/orange, and are laid on the undersides, and occasionally on top of, leaves. Leaf surfaces are covered with silk strands.

Larva : Eggs hatch into larvae in as few as 3 days. The first instar (growth stage) larvae are tiny, pale, with nearly spherical bodies and 3 pairs of legs. Larva moult and become nymphs.

Nymph : Nymphs resemble the larval stage, but are usually red or green, with 4 pairs of legs. They have oval, yellow to green to red bodies with one or more dark spots. The two nymphal stages last for 7–10 days before developing into adults.

Adult : Adults are tiny, eight-legged arthropods (related to spiders) about the size of a punctuation period. Body shape is oval to elongate-oval. Yellowish-green or reddish-orange in color and some species have 2 to 4 dark spots on the back. Adults live for up to 30 days.

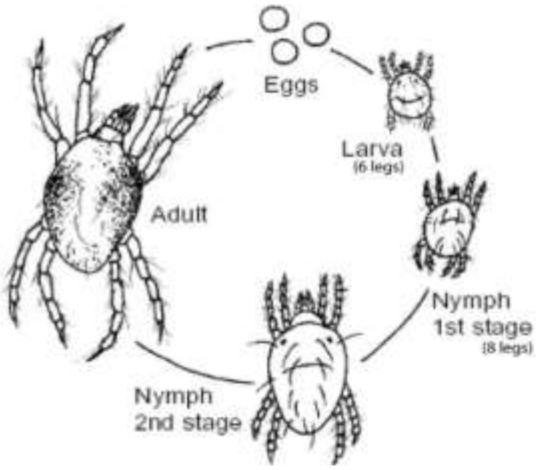
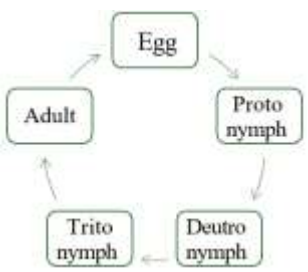


Fig. 1: life cycle of red spider mite (Ratlamwala, 2014)



Damage Caused by Mites

There are 2 types of damages caused by phytophagous mites, Direct and Indirect.

DIRECT DAMAGE : Phytophagous mites derived their food by penetrating their needle like chelicerae into leaf tissues and suck the exuding sap. The damaged leaves show light yellow spots, stippling, bronzing, curling, crinkling and finally defoliation. While feeding some eriophyids and tenupalpids inject toxins through saliva which causes malformations and deformities, gall formations, erineum, blisters, russeting, etc.

INDIRECT DAMAGE : Among the plant associated mites, the two-spotted spider mite is known to act as vector for transmitting diseases like Potato virus Y, Tobacco ringspot virus, Tobacco mosaic virus. The *Aceria cajani* cause pigeon pea sterility, *A. ficus* cause fig mosaic and *A. tulipae* cause wheat steak mosaic disease.

Fig. 2: symptoms of Potato Virus Y

Types of Mites

The most economic damage in vegetable crops is commonly caused by these 4 mites.

1. **Red Spider Mite :** *Tetranychus urticae* **,** Tetranychidae

This is a serious pest causing damage under low humidity and high temperature conditions with a wide host range infesting tomato, potato, brinjal, onion, beans and cucurbits.

Identification : Females can lay 100 or more eggs, which are spherical, clear, and colorless on the undersides of leaves protected by spider-like webbing. Larvae hatch from the eggs and have spherical, colorless bodies with three pairs of legs. Larvae moult and become nymphs, which have oval, yellow to green to red bodies with one or more dark spots, and four pairs of legs. Adults have four pairs of legs, are pale green to orange to pink to cream in color, and have two or more dark spots on their abdomens. Females have oval bodies, while males have pointed abdomens.

Biology : Adult mites oviposit on the leaves. Eggs appear creamy white, translucent and hatch within 2–4 days. The egg hatches into a larval stage and passes through protonymph and duetonymphal stages. All stages of larvae and nymphs cause damage to the leaves. Under favourable conditions, mites complete their lifecycle in 10–14 days with overlapping generations during a cropping season.

Damage : The larvae, nymphs, and adult mites feed on the undersides of leaves. They suck chlorophyll and plant sap from the leaves and inject saliva that can cause discoloration, necrosis, and leaf distortion. Small white to reddish-brown spots (stippling or speckling) appear on the upper leaf surface and the leaf can develop a dull appearance. Affected plants lose vigor, may be stunted, and defoliate prematurely. Severely infested plants may die. The loss of chlorophyll, leaf distortion, and defoliation can reduce crop yield and quality. Mites produce silken webs, initially on the undersides of leaves. However, these webs can eventually cover foliage and flowers with high mite populations. Once symptoms become visible, the mite populations are well established.

Spider mites can also vector several plant viruses. The two spotted spider mite is known to be a vector for potato virus Y on solanaceous crops, such as eggplant, pepper, and tomato. Tobacco ringspot virus and tobacco mosaic virus can also be vectored by the two-spotted spider mite.

Fig. 4 : Infestation on brinjal (Mani, 2022, p. 954)

Fig. 5 : Infestation in onion and garlic (Mani, 2022, p. 1186)

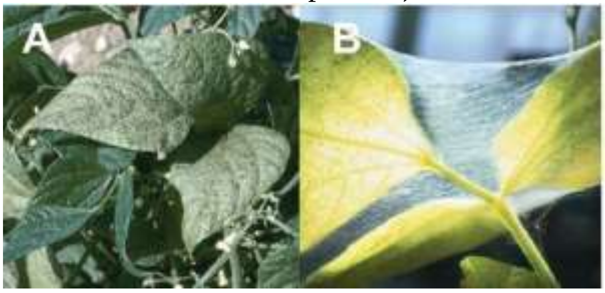


Fig. 6 : Webbing on leaves by mites
Source : [Spider Mites on Vegetable Crops (bayer.com)]

Management :

MONITORING : Successful management of spider mite infestations depends on early detection and treatment. Inspect vegetable seedlings for spider mites in the greenhouse before transplanting into the field. Look for stippling on the upper leaf surfaces and webbing on lower surfaces. Look for mites using a hand lens or tap symptomatic leaves over a white sheet of paper and inspect for crawling "dots".Scout fields frequently, especially during periods of hot, dry conditions. Initially, focus scouting efforts on field borders where mite infestations are most likely to begin. If mites are detected on the borders, then expand scouting to ten random locations within the field interior. Yellow sticky cards can also be used for detecting the presence of mites.

CULTURAL PRACTICES : Protect populations of natural enemies (predators and parasites) by limiting the use of broadspectrum insecticides, especially early in the season. Reduce plant stress by maintaining appropriate levels of fertilization and irrigation, but avoid excessive levels of nitrogen. Manage weeds, such as field bindweed, in and around the field. However, avoid mowing weeds that are already infested with spider mites, as mowing can cause the mites to migrate onto the crop plants. Try to minimize the accumulation of dust on the plants. Row covers can be used to exclude mite colonization early in the season.

BIOLOGICAL CONTROLS : Natural enemies (beneficial insects and mites) are usually able to keep spider mite populations in check on field-grown plants. The western predatory mite (*Galendromus occidentalis*), sixspotted thrips (*Scolothrips sexmaculatus),* western flower thrips (*Frankliniella occidentalis*), lady beetles (*Stethorus sp*.), minute pirate bug (*Orius tristicolor*), and lacewing larvae (*Chrysoperla carnea*) all help keep spider mite populations low. Releasing commercially available predatory mites, such as Phytoseiulus persimilis, may providesome protection for field and greenhouse-grown tomatoes, and the predatory mite *Amblyseius fallicis* is sometimes used to help manage spider mites on greenhouse-grown plants.

CHEMICAL CONTROLS : Several miticides are available to help manage spider mites on vegetable crops, but labeled products vary with crop species. Consult regional vegetable production and pest management guides and product labels for information and restrictions on application on specific crops. Applications should be initiated when spider mite infestations are first detected and symptoms on plants are observed. Applications need to reach both the upper and lower leaf surfaces to provide adequate management of spider mites.

Miticide active ingredients listed in regional vegetable production guides for use against spider mites on some vegetables include dicofol (0.2%), oomyte, wettable sulphur (0.05%), fenazaquin 10 EC at 0.01% and spiromesifen 240 SC at 0.02%. Insecticideal soaps and various horticultural oils can also be used to help manage spider mites, especially in organic production system.

Some miticides can be harmful to bees and other beneficial insects, so care should be taken in selecting and applying products for mite management. Whenever possible, apply insecticides and fungicides late in the day when pollinators are less active in the field.

1. Yellow Spider Mite :

Polyphagotarsonemus latus, Tarsonemidae

This mite infect Chilli and Potato. The broad mite, *Polyphagotarsonemus latus,* is very serious in Maharashtra and Karnataka during Kharif season and Western UP and Punjab on early planted Rabi potatoes. The mite has also been reported on potato in Gwalior (Madhya Pradesh) and Kangra Valley (Himachal Pradesh).

Biology : Eggs are laid on the under-surface of the leaves and hatch in about 2–3 days. The egg hatches into a quiescent larva that becomes a nymph in 2–3 days. The nymphs feed actively over the cell sap. When the adult females emerge out from the female nymphs, the male mates with them, and the generation continues causing damage to the crop.

Damage : The nymphs and adult form webs in the under-surface of the leaves and suck the sap resulting in downward curling and crinkling of the leaves. Infested leaves appear with elongated petioles, giving "Rat tail" symptom in chilli. The plant looks stunted with retarded growth.

Fig. 7 : damage caused by *P. latus* in potato (Mani, 2022, p. 1077)

Fig. 8 : mite damage in chilli (Mani, 2022, p. 979)

Management : The suitable crop rotation can be adopted in hot spot areas using non-host crops like wheat but not with chilli and brinjal which are susceptible hosts. Pest evasion could another best option in indo-gangetic plains that planting delayed to last week of September for early crop and during middle of October for mite incidence and damage. Destruction of severely infested plant parts during initial stages of infestation.

Encouraging the activity of predatory mite *Amblyseius ovalis* can check the mite population. Foliar spray of any one of the following insecticides, diafenthiuron 50% WP at 8.0 g/10 L, fenazaquin 10% EC at 2.0 mL/L, fenpyroximate 5% EC at 1.0 mL/L, hexythiazox 5.45% EC at 8.0 mL/10 L or milbemectin 1% EC at 6.5 mL/10 L, is useful to control the mites on chillies. Apply biopesticide abamectin at 5% for mites management. If both thrips and mites are seen together, spray of diafenthiuron or fenpropathrin 30 EC at 0.5 mL/L is very useful.

1. **Eriophyid Mite :** *Aceria tulipae***,** Eriophyidae

This mite is identified as a major damaging mite pest of onion and garlic.

Identification : . The eggs are attached to fine silk webbing. Eriophyid mites are translucent, cigar-shaped and microscopic. Nearly invisible to the unaided eye, cylindrical/cigar-shaped, tapering from head to rear, and translucent white. Unlike most mites, eriophyid only have 4 legs [2 pair] located near the head. Adult mite is about 200 to 250 µm length and width 36 to 52 µm.

Damage : Both adults and immature feed on the young leaves, and infested leaves do not open completely. Mite feeding causes stunting, twisting, curling and discoloration of foliage. Whole plants will show curling symptom, and yellow mottling is seen mostly on the edge of the leaves. This damage has been attributed to various viruses thought to be transmitted by the mites. In storage bulbs dry and desiccate.

Aceria tulipae　Twisted garlic leave due to mite damage

Fig. 9 : damage of *A. tulipae* on garlic (Mani, 2022, p. 1185)

Management : Wettable sulphur 0.3% + dimethoate (0.03%) as pre-sowing and post-sowing treatment is recommended in India for control of this pest. Seed dressing and plant treatments with 0.5% sulphur, 0.2% methomyl and 0.1% dimethoate are also effective in controlling mites. In stored garlic, fumigation with methyl bromide at 32 g/m3 for 2 h or 3 g/m3 aluminium phosphide for 72 h in airtight containers has been recommended for the control of *A. tulipae*.

1. **Bulb Mites :** *Rhizoglyphus spp., Tyrophagus spp.* Acaridae

Bulb mites damage lettuce at germination by penetrating the seed coat as soon as germination begins. This pest is most damaging when seedling emergence is slowed by cool, wet weather.

Fig. 10 : Bulb Mite (science photo library)

Bulb mites can drastically reduce plant stand, especially when lettuce follows cole crops. Management involves with crop rotation and application of complete decomposed organic matter; during winter, mite level will reduce by heavy rain or flood irrigation. Introduction of metam sodium, 6 in. deep into soil before planting, provides good control of mites living on organic matter on field.

Conclusion :

Mites pose significant challenges to the productivity and profitability of vegetable crops worldwide. However, with a comprehensive understanding of their biology, behaviour, and management options, growers can effectively mitigate the impact of mite infestations while promoting sustainable agricultural practices. By embracing integrated pest management approaches and fostering ecological balance in vegetable crop ecosystems, farmers can safeguard their crops against mites and ensure a resilient and thriving agricultural sector.

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BAMBOO INDUSTRY IN NORTH EAST INDIA

Introduction:

Bamboo is a fast growing renewal resources; that can be a sustainable substitute for wood. It improves the environment by acting as a soil and atmosphere purifier and it's dense growth helps for preventing, the soil erosion on the river bank and slopes; specially in the flood time. Bamboo is called as the "The Green gold "of the 21st Century and also known as "Poor man's timber" through which many bamboo growers become profitable on sale of different products on the market. Bamboo is deeply ingrained in the cultural and social fabric of Assam; where it is widely cultivated and used in daily life. Currently the state Govt. is actively focusing on Bamboo development through policies and missions aimed at supporting the Bamboo based industries in the state. Therefore, good type bamboo nurseries for large scale production will be the keys for success of any program related to Bamboo cultivation. Continued support from the farmer's actively on Bamboo cultivation with the rise technologies of Bamboo nurseries will definitely be helpful for getting good income from a better marketing areas; which it is very much crucial for sustainable growth of a Bamboo farm. Bamboo can be a potential source do employment generation in rural areas through manufacturing activity and utilization of local material in value added products. North Eastern region of India is endowed with abundant Bamboo resource sufficient enough to build a robust economy; besides maintaining conducive climatic conditions. Bamboo and Cane provides an important part in the live activities of the people of North Eastern Region. Different Geographical area and the Bamboo bearing area are focused in Table – 1.

Table -1 Total Geographical area and Bamboo growing area of N.E. Region of India.

North Eastern States	Total Geographical area (Sq km)	Bamboo Bearing area (Sq km)
Arunachal Pradesh	83,743	15,125
Assam	78,483	8,955
Manipur	22,327	10,687
Meghalaya	22,429	5,943
Mizoram	21,087	3,267
Nagaland	16,579	6,025
Tripura	10,477	3,617
Sikkim	7,096	1,181

Discussion:

Assam is the hub of 36 different species of Bamboo species which are suitable for producing different kinds of products viz. Bamboo shoots. Agricultural implements, Fishing equipments, Furniture, Musical Instruments, Household items and many other decorative items, Bamboo is s symbol of sustainability, culture and economic prosperity. With the effective management in Assamese Bamboo industry; there is scope to bring prosperity in the Bamboo grower's life particularly in rural area besides its normal activity in the farm. There are 5 different Bamboo spps are very much common in lower Assam (Table -2).

Table – 2: Five different Bamboo sps in Lower Assam.

Sl No	Common Name	Scientific Name	Area Covered (%)
1	Bhaluka Bamboo	Bambusa balcooa	28.55
2	Jati Bamboo	Bambusa tulda	34.15
3	KoKo or Muli Bamboo	Dendrocatamus hamiltonii	20.00
4	Bijuli Bamboo	Bambusa pallida	10.80
5	Yellow Bamboo	Bambusa Vulgaris	06.50

Now a days; it's demand is growing day by day for use in the paper industry, cottage industry as well as for bio-fuel production. While challenges like unscientific management exist, Government's Bamboo Missions and private projects are focused on improving productivity and creating value added products to realize the full potential of this renewal resource. It is mainly used for making furniture, flooring, construction materials (plywood, laminated boards) paper, Bio-fuel, Eco-friendly products (straws, water bottle, disposable items etc). Bamboo farming profit range from Rs. 1 lakh to Rs. 10 Lakhs per acre annualy with significant earning potential after the 5th year. Once the plants are fully matured harvesting could be done. Early stage harvesting in Bamboo gives less profit. But it can be increased by selling Nursery plants; which can generate Rs. 60,000.00 only per acre in the second year. The profit is highly dependant on market price, yield and expenses behavior, which can vary by species and locations.

Most important thing is that Bamboo grows rapidly and is highly resilient to environmental fluctuation ensuring a steady source of revenue. Bamboo is silent warrior against the climate change. It's fast growing nature makes it an excellent carbon sink, capable of absorbing vast amount of CO_2 . Bamboo has emerged as a promising source of Bio – fuel.

Since the beginning of the Civilization, Bamboo has played an important role in daily lives of many farmers in India. Bamboo craft is one of the oldest cottage industry, primarily due to versatility, strength, lightness and easy workability of bamboo with simple hand tools. Now a days, it is also used in bio-fuel production in huge quantities in our country. During the last decade technologies for manufacturing new materials were also developed and few industries were also established by our Government. However, there are many uses of bamboo in this country. There are scope to prepare huge quantities of bamboo products and articles in future. It is necessary to arrange some quality oriented training program by the government of Assam, as well as ICAR, New Delhi for the rural youth of Assam in near future about the uses of bamboo for development of small scale industries. Bamboo cultivation may be brought under the Employment Guarantee scheme (EGS) as followed in many states like Maharashtra, Kerala, Tripura, Mizoram, etc. in our country. Therefore, necessary research works needs to be undertaken on this aspects. We must be serious about the propagation techniques viz. Offset, Rhizomes cutting techniques, Culm cutting techniques and micro propagation techniques. This propagation techniques are widely followed in different places of our country at present (Table-3).

Table – 3 Methods / Techniques used for propagation of Bamboo

Methods/Techniques	Used by different countries
Offset, Rhizomes	India, Bangladesh, Sri Lanka
Culm cutting, split culm cutting	India, Philippines, Thailand, Sri Lanka
Marcotting, Ground layering	Bangladesh, Philippines
Micro Propagation	India, China, Thailand

Main bamboo growing districts in Assam.are – Cachar, Karbi Anglong, Dimasa, Nagaon, Morigaon, North Lakhimpur, Biswanath Chariali, Goalpara, Bongaigaon, Kokrajhar and Barpeta. Bamboo can be grown well as a farm crop, because of its various uses, viz. an a) Exclusively for their edible shoots, b) It is also grown for its dual purposes. i) they can be grown for mature culm, ii) they can be utilised as young shorts, (bamboo) c) they can be grown exclusively as mature plants; which are sold in the daily market. Besides these - it is also grown with different integrated farm models. (i) Bamboo + Tea (ii) Bamboo grown by maintaining the proper distance with other trees (viz -Jackfruit, Mango, Simalu, Acasia, Neem, Eucalyptus, Amlokhi etc) for medium and large type farmers of Assam (iii) Bamboo+ Fishpond, and (iv) Bamboo grown with other edible fungi or medicinal plants.

Finally, success in bamboo farming depends on careful planning, right selection of varieties, good soil, type, and right time of planting and harvesting that will definitely lead to earn good income annually.