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Impact of Global Markets on Local Crop Prices

[1]Dr. Vishwas Deep, [2]Dr. Khan Chand, [3]Manjul Jain

[1]Assistant Professor, Department of Agribusiness, Bhai Gurdas Degree College Sangrur, Punjab

[2]Professor, Department of Agricultural Engineering, School of Agricultural Sciences, Nagaland University, Medziphema Campus, Distt: Chumukedima, Nagaland

[3]Assistant Professor, Department of Agronomy, School of Agriculture, Eklavya University Damoh, Madhya Pradesh

This bulletin examines the impact of international market forces on local commodity prices, which affect farmers, consumers, and national food security. Major world drivers—like changes in supply-demand balances, trade policies, and currency movements—cause price movements to ripple across borders. Case studies in India, Nigeria, and Argentina show the different effects. The bulletin also identifies reactions such as government intervention, farmer adjustment, and infrastructure investment. It ends with policy suggestions to increase resilience and promote fair pricing in a growing interdependent agricultural economy. A comprehension of these global-local processes is necessary for sustainable development and fruitful agricultural planning.

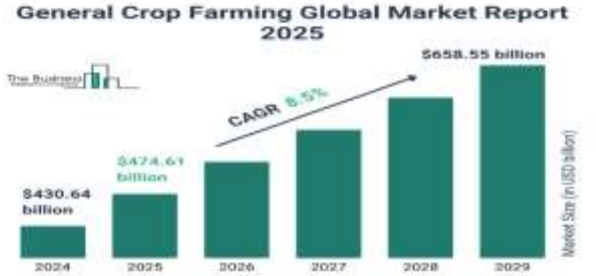
Introduction

The interconnection between international markets and domestic crop prices has become more intricate and integrated over the past few decades. As trade in agriculture has increased across borders, local farmers and consumers are today more exposed to international economic fluctuations, supply chain issues, and global trade dynamics. What were primarily regionally isolated markets a few decades ago are now highly integrated within an international system driven by demand volatility, geopolitical phenomena, and climate uncertainty. Yang *et.al.* 2008.

Local farm prices are no longer determined or isolated by local conditions like harvest output or national policy. Rather, prices of staple items like wheat, maize, soybeans, and rice are shaped by variations in international patterns of consumption, fluctuations in trade policy like tariffs or export prohibitions, and even macroeconomic indicators like currency exchange rates. For instance, a drought in a leading exporting nation may lower world supply and have a ripple effect that increases prices globally, even for countries not directly impacted by the weather condition.

This connection with international markets also invites speculation on commodity exchanges, which further destabilizes prices for local farmers who do not have the resources or means to hold that risk. Globalization can bring access to greater markets and better income possibilities for farmers, but it also subjects them to uncertain international forces outside of their control.

Understanding how global markets influence local pricing is essential for developing effective agricultural policies, ensuring food security, and protecting farmer livelihoods. Policymakers, agricultural cooperatives, and development organizations must work together to create adaptive strategies that respond to these global-local interactions, support farmer resilience, and promote price stability in domestic food systems. Smale, *et.al.* 2009.



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3.Global Market Dynamics

The global market forces strongly influence domestic crop prices through several interlinked economic and policy channels. It is crucial for all agricultural value-chain stakeholders—farmers, traders, and policymakers alike—to comprehend these forces.

1. Global supply and demand changes

The underpinning of price behavior in the agricultural markets is global supply and demand. As global population increases—projected to reach more than 9 billion in 2050—so too is demand for staple grains such as wheat, rice, maize, and soybeans. Diet changes in developing economies are also changing patterns of consumption. In much of the developing world, incomes are improving, stimulating increased consumption of meat, and through this, indirectly driving demand for feed crops like maize and soybeans. This global consumption pattern puts upward pressure on prices and impacts local markets even in nations that aren't significant exporters or importers. Dillon *et.al.*2016.

Source: http://capreform.eu/decreasing-food-prices-short-term-happiness

2. International Trade Policies

Trade policies have a significant impact on shaping the flow of farm products across borders. Tariffs, export restrictions, and government subsidies distort global price signals and create uncertainty in local markets. A good example is the U.S.–China trade war, in which China taxed U.S. soybeans, causing an overabundance in the U.S. and redirecting purchases to Brazil and Argentina. This abrupt shift in trade patterns impacted soybean prices worldwide, showing how two nations' geopolitical choices can create far-reaching ripple effects on farmer revenues elsewhere.

3. Exchange Rates of Currency

Currency fluctuations equally impact crop prices heavily. A weakening local currency makes a country's exports cheaper and more attractive on the international market, potentially raising farm-gate prices. However, it also increases the cost of imported agricultural inputs such as fertilizers, seeds, and machinery. This dual effect can squeeze profit margins for local farmers and cause inflation in domestic food prices. Consequently, relative strength or weakness of a local currency can cause discrepancy between international commodity prices and local retail prices, making markets unstable and less predictable.

4.Impact on Local Crop Prices

The impact of international markets on domestic crop prices is realized through a number of complicated and frequently volatile mechanisms. As much as globalization provides opportunities for trade and revenue, it also introduces volatility in domestic agricultural economies. Learning how international dynamics are translated into local price adjustments is central to creating robust and adaptive food systems. Baffes, *et.al.*2015.

1. Price Transmission Mechanism

One of the major mechanisms through which global markets influence local prices is the process of price transmission. When international prices for key crops such as wheat, soybeans, or maize rise or fall, local prices tend to move in the same direction. Yet the extent and rapidity of transmission differ widely depending on the crop, the organization of local markets, and the integration of the global trading system by the country. For instance, an international surge in wheat prices will increase bread prices even in nations that are not highly dependent on imports because of international reference points and psychological anticipations in the market. In contrast, in isolated markets with low exposure to trade, this impact can be delayed or suppressed.

2. Volatility and Uncertainty

Domestic farmers and consumers are also facing more exposure to price volatility resulting from global factors. Occurrences like droughts in major producing areas such as the U.S., Ukraine, or Brazil are capable of evoking instantaneous global supply shocks, leading to quick price increases. Apart from natural causes, financial speculation on international commodity markets has the effect of creating artificial price peaks. Institutional players tend to use commodities as short-term profit-making assets, and their tendency to buy and sell can lead to a sharp price fluctuation irrespective of real supply and demand.

3. Seasonal and Structural Factors

In spite of worldwide pressures, domestic realities like the local cycle of harvests, storage capacity, transportation networks, and local weather conditions play a crucial role in determining how global prices are local reflections. A local harvest bumper crop can cause an oversupply situation temporarily, driving prices lower, even where there is a shortage situation in the rest of the world. Even weak roads or scarcities of storage facilities can cause post-harvest losses, reducing farmers' capacity to take advantage of higher worldwide prices.

5. Case Studies

Case studies show the ways in which international market forces combine with local conditions and national policy to determine crop prices. The three cases below—from India, Nigeria, and Argentina—show the different ways that local agricultural markets are driven by international forces.

Case 1: India – Wheat and Rice

India's farm sector is heavily connected with international food trends, particularly in staple crops such as wheat and rice. Over the past few years, international prices of rice shot up because of weather abnormalities fueled by El Niño, which affected rice yields in major exporting nations. Consequently, one of the world's largest exporters of rice, India, came under added stress on domestic procurement and food subsidy schemes, which are vital to food security and price management. India retaliated by imposing export controls on non-basmati rice in 2023 in order to safeguard local stocks and contain inflation. The policy, though, had a far-reaching international impact—prices of rice in African nations and Southeast Asia skyrocketed, showing how a nation's domestic choices may have implications for international markets. India's dual identity as both a world influencer and an internationally price-trend-affected country makes it an interesting case of two-way price transmission.

Case 2: Nigeria – Maize and Soybean

Nigeria's farm market mirrors the woes of import dependence and exchange rate instability. The biting devaluation of the Naira over the last few years, coupled with government bans on agro- imports to promote local self-sufficiency, caused severe price hikes for key crops such as maize and soybean. To this effect, increased international prices of soybean drove up the prices of livestock feed that is based on soybeans, impacting poultry and dairy farmers who also depend primarily on maize. This added to inflationary pressures within the food chain. These trends highlight the ways in which global market fluctuations and local monetary interventions can interact to push local food prices out of the reach of smallholder farmers and consumers.

Case 3: Argentina – Soybean and Corn

Being one of the biggest exporters of soybean and corn in the world, Argentina's crop prices are directly linked to international commodity markets. Farmers reap immediate benefits from international high prices since they produce mainly for export. Yet, the Argentinian government levies export taxes to manage local inflation and local affordability of food. Although the policies may assist in stabilizing local prices for buyers, they minimize producers' profit margins, at times deterring production and investment in agriculture. This example shows the dilemma between export revenue maximization and domestic food price stability within an interconnected world economy.

6.Responses and Policy Implications

As local crop prices are more and more influenced by global market forces, a comprehensive response to safeguard farmers and consumers from extreme volatility as well as long-term market disequilibrium is warranted. Policymakers, development agencies, and the private sector need to act together to enact policies that enhance resilience, efficiency, and equitable engagement in world markets. The following are three essential response areas: government intervention, farmer adaptation, and infrastructure development.

1. Government Intervention

Governments have a range of tools at their disposal to manage price volatility and protect food security. Price support schemes, export bans, and the use of strategic grain reserves are frequently used to stabilize domestic markets. For instance, many countries stockpile staple grains to release into the market during price spikes or poor harvests. Export restrictions, like India's 2023 rice ban, are sometimes implemented to safeguard domestic supply. Yet, whereas such interventions can provide temporary relief, excessive or inapt policies might distort markets, discourage private sector investment, and damage long-term competitiveness. Sometimes subsidies and market controls generate inefficiencies that discourage innovation and motivate farmers.

2. Farmer Adaptation

Farmers themselves play a crucial role in managing price risk. They can be encouraged to diversify—planting several crops instead of a sole commodity—to lower exposure to global price variability. Moreover, financial products such as futures contracts and crop insurance provide farmers with the opportunity to hedge against projected loss or price decline. Timely market information, both at a local and global level, enables farmers to make informed decisions about when and where to sell their crops. Mobile technologies and digital platforms are increasingly becoming part of bridging information gaps and enhancing resilience at the farm level. Brown *et.al.* 2008.

3. Investment in Infrastructure

Strategic investment in farm infrastructure has the potential to enhance market performance substantially. Inadequate post-harvest storage frequently results in losses or distress selling at low prices, particularly in rural markets. Enhancing storage facilities, cold chains, and processing units maintains the quality of crops and enables farmers to sell when the prices are better. Additionally, better roads, railways, and port access reduces costs of transport and facilitates smallholders' participation in international markets. Infrastructure not only facilitates access to markets but also national competitiveness in agricultural exports.

7.Conclusion and Recommendations

The international agricultural market increasingly influences what local farmers receive and what people pay. Though such interdependence brings new avenues for trade and income, it also makes the local economy vulnerable to price volatility, climate shocks, and changes in external policies. To manage these forces, action and coordination are needed.

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Recommendations:

- Implement national crop price monitoring and early warning systems.
- Foster access by farmers to crop insurance and financial hedging instruments.
- Seek out free trade agreements with protection of sensitive agri-food industries.
- Bolster regional trade partnerships in order to minimize dependency on remote markets.

Call to Action

Policymakers, civil society organizations, and farmers will have to collaborate to develop robust agricultural systems that can sustain themselves in the context of a globalized economy. Reading and reacting to world market cues is no longer a choice but a strategic imperative for sustainable development and food security.

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Thriving Through Change: Odisha's Climate-Resilient Crop Revolution

Satya Pragyan Kar[1]* Dr. Pragyan Kumari[2]

[1]Ph.D. (Ag.) Scholar, Department of Agricultural Meteorology, Birsa Agricultural University, Kanke, Ranchi, Jharkhand

[2]Assistant Professor cum Junior Scientist, Department of Agricultural Meteorology, Birsa Agricultural University, Kanke, Ranchi, Jharkhand

Odisha's agricultural sector is undergoing a transformative shift amid escalating climate challenges, including erratic monsoons and extreme weather events. This article explores the emergence of climate-resilient crop varieties, such as drought-tolerant DRR Dhan 44 and flood-tolerant Swarna Sub1, developed to sustain yields under adverse conditions. Supported by the National Food Security Mission (NFSM), these innovations have enabled 1.5 lakh farmers to boost productivity by 20% in drought-prone regions like Kalahandi in 2024. Through real-life accounts from farmers and data on water savings and income growth, the piece highlights the practical benefits for rural communities. Additionally, it addresses ongoing challenges, such as limited adoption, and outlines future plans, including seed distribution and training initiatives. Aimed at farmers and agricultural students, this article underscores the potential of resilient crops to secure Odisha's farming future in a changing climate.

Introduction

Odisha's agricultural sector stands at a pivotal moment, grappling with escalating climate challenges such as erratic monsoons, rising temperatures, and frequent floods. In 2024, western Odisha experienced a 1.5°C temperature surge, reducing rice yields by 12% in Bolangir, while Jagatsinghpur saw 50,000 hectares submerged due to flooding (IMD, 2025). Yet, a transformative wave is sweeping through with climate-resilient crop varieties like drought-tolerant DRR Dhan 44 and flood-tolerant Swarna Sub1. Supported by the National Food Security Mission (NFSM), these innovations have empowered 1.5 lakh farmers, boosting productivity by 20% in drought-prone regions like Kalahandi in 2024. This article examines how these crops, bolstered by recent technological and policy advancements, are reshaping farming for rural communities and students, offering a sustainable path forward in a changing climate.

A New Era of Crop Innovation

Climate change is rewriting the rules of agriculture, with traditional water-intensive paddy struggling under a 20% rainfall deficit during the 2024 monsoon in parts of Odisha (OSDMA, 2025). The Central Rice Research Institute (CRRI) in Cuttack has responded with resilient varieties. DRR Dhan 44, released in 2022, thrives for 15 days without rain due to its deep roots and water-efficient traits. Swarna Sub1, designed for flood-prone areas, withstands 14 days of submergence (CRRI, 2025). A new hybrid, DRR Dhan 45, piloted in Koraput since June 2025, promises 6 tons per hectare under severe drought conditions.

The NFSM, revamped in 2023 with a ₹5,000 crore budget, has driven this revolution. In 2024, it supported 1.5 lakh farmers across 15 districts, achieving a 20% yield increase in Kalahandi and Bargarh (MoAFW, 2024). By June 2025, NFSM expanded its scope, integrating organic inputs to enhance soil health and launching a mobile van initiative to reach remote areas. This scheme provides seeds, training, and subsidies, making resilience accessible to smallholders and fostering a scalable model of climate-smart agriculture.

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Real-Life Success Stories

The impact of these crops is vividly captured in farmer experiences. In Mayurbhanj, Ramesh Mahato adopted DRR Dhan 44 in 2024. “Last year’s drought destroyed my paddy, but this year, despite 10 dry days, I harvested 5 tons per hectare,” he shares, attributing success to the crop’s resilience and NFSM training. In Puri, Laxmi Behera grew Swarna Sub1 during the 2024 floods. “My rice survived two weeks underwater, yielding 4.5 tons per hectare,” she notes, thanking NFSM support. In Koraput, Suresh Nayak, part of the DRR Dhan 45 pilot, reports, “This new variety gave us hope in a 12-day drought, with early signs of 5.8 tons per hectare.”

These varieties offer more than survival. DRR Dhan 44 matures in 110 days, 10 days faster than traditional rice, enabling double cropping. Swarna Sub1 reduces methane emissions by 15%, supporting climate goals (ICAR, 2025). By June 2025, adoption reached 12,000 hectares, cutting water use by 25% and pesticide reliance by 5%, with DRR Dhan 45 trials showing a 6% reduction (CRRI, 2025). This month, 500 farmers in Koraput reported improved soil moisture retention, a bonus for arid regions.

Benefits for Farmers and Students

For farmers, these crops deliver stability and savings. DRR Dhan 44 requires 30% less irrigation, saving ₹5,000 per hectare on water costs, while Swarna Sub1 prevents total loss during floods, preserving income. NFSM’s 2024 data shows a 15% income rise for adopters in Ganjam, with June 2025 figures adding a 5% increase due to rising demand for resilient grains (MoAFW, 2024). In Balasore, labor costs dropped 10% due to faster maturity cycles.

Students are integral to this shift. CRRI’s training program, enhanced with virtual modules launched in May 2025, now engages 500 students monthly, teaching crop management and app-based data analysis. A June 2025 ICAR survey found 70% of participants plan to promote these varieties locally. Internships with AgriTech Odisha startups, offering real-time weather insights, further equip students for a tech-driven future.

Table 1: Performance of Climate-Resilient Crops in Odisha (2024-2025)

Crop Variety	Trait	Yield (tons/ha)	Water Saving (%)	Adoption Area (ha)	Pesticide Reduction (%)
DRR Dhan 44	Drought-tolerant	5.0	30	6,000	5
Swarna Sub1	Flood-tolerant	4.5	20	4,000	3
DRR Dhan 45 (Pilot)	Drought-tolerant	6.0 (est.)	35	500 (pilot)	6 (est.)

Source: CRRI, 2025; MoAFW, 2024; ICAR, 2025

Table 2: NFSM and Policy Impact in Odisha (June 2025)

Initiative	Target (2025-2026)	Current Progress (June 2025)	Beneficiaries	Economic Benefit (₹/ha)
Seed Distribution	50,000 tons	10,000 tons distributed	50,000 farmers	7,000 (subsidy)
Farmer Training	2 lakh farmers	75,000 trained	75,000 farmers	2,000 (income boost)
Climate-Smart Fund	1 lakh hectares	20,000 ha subsidized	10,000 farmers	5,000 (cost saving)
Carbon Credit Program (FAO)	10,000 farmers	2,000 enrolled	2,000 farmers	2,000 (incentive)

Source: MoAFW, 2024; FAO, 2025; OSDMA, 2025

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Figure 1: DRR Dhan 44 in Kalahandi- Source: ICAR, 2025

Figure 2: Swarna Sub1 Field- *Source: CRRI, 2025*

Figure 3: DRR Dhan 45 Pilot in Koraput- *Source: CRRI, 2025*

The Future of Farming

Adoption remains limited, with only 10% of Odisha's 4.5 million farmers using these varieties, hampered by seed shortages and awareness gaps (ICAR, 2025). The NFSM's June 2025 plan includes distributing 50,000 tons of seeds by 2026 and training 2 lakh farmers, with mobile vans reaching remote Malkangiri. AgriTech Odisha's app, updated this month, now serves 5,000 users with weather predictions and planting guides. A June 25, 2025, collaboration with IIT Bhubaneswar introduces AI-driven crop monitoring, aiming to cover 20% more farmland by 2027.

The Odisha government's ₹1,000 crore Climate-Smart Agriculture Fund, launched this month, subsidizes 50% of seed costs, targeting 1 lakh hectares by 2028. The FAO's carbon credit program, piloted with 2,000 Swarna Sub1 farmers, offers ₹2,000 per hectare, incentivizing sustainable practices (FAO, 2025). These efforts signal a robust framework for scaling resilience.

Challenges and Opportunities

Seed production lags, with CRRI facing a 30% shortfall in 2025 despite increased output (CRRI, 2025). Awareness campaigns, including radio broadcasts in 10 dialects launched this month, aim to educate 1 lakh farmers by December. Market linkage is a hurdle—resilient grains command a 10% premium, but only 20% reach urban markets due to logistics. E-marketplaces by startups, projected to connect 10,000 farmers by 2026, are bridging this gap. Additionally, a June 2025 study by ICAR suggests integrating drip irrigation with DRR Dhan 44 could save 40% more water, a potential game-changer.

Conclusion

Odisha's climate-resilient crop revolution exemplifies innovation and community resilience. With DRR Dhan 44, Swarna Sub1, and the promising DRR Dhan 45, farmers like Ramesh, Laxmi, and Suresh are thriving despite climate adversities, supported by NFSM, policy initiatives, and technology. Students, this is your moment—engage with training, harness app-based tools, and lead this transformation. Together, let's cultivate a sustainable, prosperous agricultural future for Odisha.

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Digital technology in Indian Agriculture

Mr. Madhav Dhakal[1], Dr. Minali Banerjee[2] and Dr. Monika Mathur[3]
[1]Research Scholar, [2]Assistant Professor, [3]Associate Professor,
Department of Economics at Manipal University Jaipur.

The history of agricultural digital technology started in the 20th century when connectivity, big data, computers, the Internet of Things, the Internet, and mobile phones became more accessible. These developments ushered in a new phase of agriculture, in which data contributes to decision-making and improving farming practices globally. Agriculture is crucial to the Indian economy, providing employment opportunities for nearly 58% of the people. The application of emerging digital technologies to Indian agriculture has been increasing. The agri-tech startups have increased from 63 to more than 2,800 between 2010 and 2023. The growth results from increasingly informed farmers, more individuals receiving internet connectivity, and the diffusion of mobile phone technology to rural regions. The government has promoted technology and innovation in farming. On our recent trip to Rajasthan's Sikar district, we met farmers willing to adopt new technology.

Farmers know about digital means such as drones and sensors, and weather forecasting apps. They all have smartphones and access agriculture apps and view farming videos on social media. But there is still a lack of digital literacy that proves to be a major hindrance to adopting these technologies. Digitally literate farmers are keen on innovation. They call agriculture experts with their mobiles and view educational videos and news, reflecting their interest in using technology to access knowledge. There is access to smartphones and cheap mobile data, symbolizing their preparedness for digital technology in India. Though open to new technologies, they are not able to access them easily. They look for governmental assistance in the form of subsidies and training initiatives.

The problem is in converting elementary digital literacy to efficient use of sophisticated agricultural technology. Although farmers understand drones and sensors, their practical experience remains limited in using them for farming. These devices tend to favor large-scale farmers because small farmers cannot afford the exorbitant charges. Farmers will invest in such technology only if they are sure that these technologies will increase their productivity and pay for themselves. This is what creates a major barrier, making most people stick to the traditional ways even when there are benefits offered by such technological advancements. Farmers are practical-minded people who require certainty that digital options like drone-based crop monitoring or sensor-based irrigation will make tangible positive differences on their farms. Greater yields, improved resource use, and higher profits are important incentives for them to embrace new technologies. Additionally, farmers seeking workers during harvest require speedy solutions.

Closing the gap demands an approach that is multi-faceted. Government assistance through specific subsidies can bring essential digital hardware within reach, improve digital infrastructure in rural regions, and encourage farmers to make the initial move. Not all programs will empower farmers.

A. Establishing digital literacy provides farmers with the fundamentals to use smartphones and access useful information on the web. This includes the use of apps for weather, market prices, and simple farm calculations. Because farmers mostly have smartphones, this is possible.

B. Technology demonstrations will demonstrate obvious applications of these devices. Their practical applications, important to their farming businesses, should be emphasized during these sessions. For example, rural women in India have been trained under the government's Namo Drone Didi scheme to operate drones for farming. This initiative allows rural farmers to witness live examples and realize the advantages, and this increases interest and uptake.

C. Learning by doing through practical workshops teaches farmers how to use essential digital tools and collect the necessary data for their farms. This hands-on approach builds their confidence and empowers them to use these technologies independently.

D. Local networks can recognize innovative farmers successfully utilizing digital solutions and ask them to mentor others. These champions are key community assets, can share their information, and drive adoption at scale.

Addressing the major challenges within agriculture is critical as it creates avenues for pushing forward digital farming. Farmers have largely built good digital skills and are eager to adopt new technologies. We must labor to close the persistent digital divide, which restricts the full potential of these talented agricultural experts. Consider that all farmers, big and small, possess the ability and resources to employ digital technology effectively. This is not a dream; it can be reality with the right plan. We can help farmers better understand the complexities of digital innovation and integrate these technologies into their everyday activities by financing training programs and resources. This approach has numerous benefits. It is possible to achieve a more productive, efficient, and sustainable agriculture when we actively enhance farmers' digital competencies. Both large agribusinesses and small family farms will benefit from this transformation, which will consolidate the agricultural sector and enhance innovation. Ultimately, we can build a future in which farmers survive but thrive, to the benefit of our economies, communities, and environment in tangible terms. We must strive for this future, where digital agriculture is integrated into modern farming practices to ensure a prosperous future for everyone. Together, we can achieve this vision and harness technology's incredible potential to enhance the agricultural sector.

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Fungal Elicitors in Agriculture: Paving the Way for Eco-Friendly Plant Disease Control

Damini Patel[1], Tarun Kumar Meena[2], Kinjal Mondal[3]
[1]Department of Plant Pathology, Maharana Pratap University of Agriculture and Technology, Udaipur, Raj.
[2]Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana-Punjab
[3]Department of Molecular Biology & Biotechnology, Maharana Pratap University of Agriculture and Technology, Udaipur, Raj.

Plant diseases represent a substantial danger to global food security in the face of climate change, which is exacerbated by intensive farming practices and the inappropriate use of conventional pesticides. Nowadays, the application of fungi-based elicitor molecules on plants is praised for protecting them from hazardous intruders. Fungal elicitors, unlike conventional pesticides, are non-toxic to the environment and reduce the risk of insect resistance. They function by activating systemic acquired resistance (SAR) via pathogen-associated molecular patterns (PAMPs). When these elicitors are identified by plant pattern recognition receptors (PRRs) on the cell membrane, they initiate PAMP-triggered immunity (PTI). This activation influences signalling cascades, which eventually stature the production of defense-related genes, priming the plant for increased resistance. Future perspectives emphasize fungal elicitor-mediated disease control as a green alternative that has the potential to revolutionize crop protection by improving stress resilience and lowering the need for hazardous pesticides, hence encouraging sustainable agriculture.

Introduction

Outbreaks of plant diseases cause primary production and biodiversity to be lost, which has a detrimental effect on the socioeconomic and environmental circumstances of the impacted areas. These outbreaks also represent serious threats to global food security and environmental sustainability. Because it changes host-pathogen interactions and pathogen evolution, as well as makes it easier for new pathogenic strains to arise, climate change further raises the danger of outbreaks. Plant diseases cause significant annual food crop production losses (empirically about 10.1-28.1% for wheat, 24.6-40.9% for rice, 19.5-41.1% for maize, 8.1-21% for potatoes, and 11-32.4% for soybeans), resulting in species diversity loss and downstream impacts on human health (Savary *et al.,* 2019). In this scenario, the extensive application of conventional agrochemicals remains the sole option for controlling plant disease infestation. However, their commercial application is inefficient, and some have been shown to be carcinogenic. On this point, we require an innovative method to increase our mechanistic knowledge of pathogen distribution in future climates, reduce the danger of disease outbreaks, and secure long-term food security.

Unlike traditional pesticides, elicitors provide a more sustainable solution, lowering environmental effect and reliance on chemicals. They improve plant resistance to a wide range of diseases while increasing growth and production. Recent advances in biotechnology have broadened its applicability, allowing for more precise delivery and effectiveness. The use of elicitor molecules aids in plant disease control by activating plants' innate immune responses. When elicitors are detected by particular receptors on plant cell surfaces or within cells, they initiate a cascade of signalling pathways. This leads to the synthesis of defense-related chemicals such phytoalexins, reactive oxygen species (ROS), and pathogenesis-related (PR) proteins. Furthermore, elicitors reinforce cell walls by stimulating callose and lignin deposition, forming physical barriers to pathogens. They also cause induced systemic resistance (ISR), which allows plants to protect against a wide spectrum of diseases (Guo and Cheng, 2022).

1. What are elicitors?

Plants respond to stress by producing more secondary metabolites when exposed to elicitors, which can be produced from both living (biotic) and non-living (abiotic) sources (Figure 1). Initially, the word "elicitor" was used to describe compounds that particularly promote the synthesis of phytoalexins. It today, however, widely includes any substances that trigger plant defences. At low concentrations, elicitors function as signal chemicals that bind to particular receptor molecules and alert the plant to initiate defence (Figure 1). Despite having same origin, elicitor molecules work completely in different fashion than the toxin does (Sharma and Shahzad, 2013). Toxins are virulence factors produced by pathogens to disrupt cellular processes, causing direct damage like necrosis and chlorosis to facilitate infection. While elicitors are beneficial and strengthen plant defense, toxins are harmful and weaken plants. Understanding these distinctions is critical for advancing plant disease management, where elicitors can be leveraged as sustainable tools to enhance plant immunity against notorious biotic pressure.

Figure 1 Elicitor binds with receptors and induces secondary metabolite production which further aligns to control environmental stress

3. Fungal elicitors: relevance in plant disease management

Fungal elicitors are low molecular weight chemicals that are abundant in chemical signalling substances, including glycolipids, glycoproteins, fatty acids, oligosaccharides, chitin, proteins, peptides, and polysaccharides. They trigger plant defence systems by speeding up the manufacturing of phytoalexins and hypersensitive reactions during disease resistance (Zhang *et al.,* 2022). These powerful substances comprise a variety of fungal products, such as fermentation broths, metabolites, degradation fragments, and secreted compounds, all of which have the ability to affect essential metabolic processes or initiate defence responses in plants. Their diverse nature and functional versatility make fungal elicitors key players in both ecological interactions and biotechnological applications (Guo and Cheng, 2022). Based on their chemical composition, fungal elicitors are broadly classified as mentioned below (Table 3.1).

Table 3.1 Classification of Fungal Elicitors

Category	Type	Origin	Salient features	Function
Saccharide elicitors	**Chitin**	Fungal cell walls	A homopolymer of N-acetylglucosamine (GlcNAc) units, forming long, linear chains. It constitutes the primary structural component of fungal cell walls, contributing to mechanical strength and resistance against osmotic pressure.	Induces pathogen-associated molecular pattern (PAMP), triggering plant immune responses by activating the defense-related enzymes like lipoxygenase.
	Chitosan	Fungal cell	A derivative of chitin that has been partly deacetylated,	Stimulates plant defense mechanisms by inducing phytoalexin accumulation,

		walls	consisting of randomly dispersed units of N-acetyl-D-glucosamine and β-(1→4) linked D-glucosamine. It is biodegradable, biocompatible, and non-toxic in nature.	callose deposition, and activation of systemic acquired resistance (SAR) pathways.
	Cyclodextrin	Fungal cell walls	Cyclic oligosaccharides structurally made up of glucose units linked by α-1,4-glycosidic bonds. Their hydrophobic cavity allows the encapsulation of hydrophobic molecules.	Promotes the biosynthesis of secondary metabolites, such as polyphenols and flavonoids, which contribute to plant defense against pathogens and environmental stress.
Protein elicitors	**Cell wall-related enzymes**	Fungal cell walls	A group of enzymes that break down polysaccharides in fungal cell walls, such as polysaccharide lyases (PL), glycoside hydrolases (GH), and carbohydrate esterases (CE).	Elicit plant resistance by breaking down fungal cell wall components.
	NEP1-like proteins	Fungal culture filtrates	Small, secreted proteins from fungi that induce necrosis and stimulate ethylene production in plants. They mimic pathogen attack and trigger cell death pathways.	Act as elicitors of plant immune responses by inducing necrosis and activating pattern-triggered immunity (PTI) in dicot plants through recognition of conserved molecular patterns.
	Harpin proteins	Various Fungal species	Glycine-rich, heat-stable proteins secreted by various pathogenic fungi, known to play a significant role in plant-microbe interactions.	Stimulate the hypersensitive response (HR) in plants, leading to the generation of ROS, ion fluxes, and initiation of defense signaling pathways.
	Glycoprotein	Fungal culture filtrates	Proteins with covalently attached carbohydrate moieties, secreted by fungi to modulate plant immune responses.	Induce chitinase activity, lipid peroxidation, and hypersensitive response (HR), strengthening plant cell walls and enhancing resistance to pathogen invasion.
Poly-unsaturated fatty acids	**Arachidonic acid**	Fungal extracts	A polyunsaturated fatty acid derived from fungal cell membranes, known for its role as a signaling molecule in both plants and animals.	Acts as an elicitor of phytoalexin production in plants, inducing the synthesis of sesquiterpenoid phytoalexins, which serve as antimicrobial compounds in plant defense against pathogens.

(Source: Guo and Cheng, 2022)

The elicitors also prime crops for accelerated and amplified responses upon pathogen attack. Their integration into integrated disease management (IDM) strategies reduces the dependency on synthetic fungicides, promotes broad-spectrum disease resistance, and is compatible with biological

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control agents and cultural practices. A study conducted by De Vega *et al.* (2020), revealed how chitosan-treated tomato plants showed enhanced resistance to *Botrytis cinerea* (gray mold) as compared to untreated ones (control). The elicitor induced the accumulation of defense-related enzymes like peroxidase and polyphenol oxidase while also priming systemic acquired resistance. In grapevines, β-glucan treatment activated PTI, increasing levels of phytoalexins and pathogenesis-related proteins. Studies showed effective protection against *Plasmopara viticola* (downy mildew) under greenhouse and field conditions (Koledenkova *et al.,* 2022). In another study, application of functional oligosaccharides extracted from *Sclerotinia sclerotiorum* on soybeans was found to induce defense-responsive gene expression, leading to increased lignin deposition and enhanced cell wall fortification (Swaminathan *et al.,* 2022). These case studies highlight the versatility of fungal elicitors in promoting plant immunity, reducing dependency on chemical inputs, and integrating with other IDM practices.

4. Fungal elicitors as potential bio-weapons: Mode of Action

Plant immunity has changed significantly since H.H. Flor's 1942 "gene-for-gene" idea was put forward, leading to the development of several models that describe interactions between plants and pathogens. Among them, the zigzag model has emerged as the "central dogma" in plant immunology, giving a clear framework for how plants detect and protect against pathogens (Dodds *et al.,* 2024). This model depicts PAMP-triggered immunity (PTI) as the plant's first line of defense, which is activated when conserved pathogen compounds called pathogen-associated molecular patterns (PAMPs), including bacterial flagellin or fungal chitin, are recognized by pattern recognition receptors (PRRs) on the plant cell surface. This identification sets off a rapid defense reaction that involves the production of reactive oxygen species (ROS), calcium influx, activation of genes linked to defense, and the development of physical barriers like callose deposits. Fungal elicitors stimulate plant defence systems by triggering PTI responses (Figure 2) (Guo and Cheng, 2022). They enhance systemic acquired resistance (SAR) for long-term protection and prepare plants to respond faster to future threats. Their involvement in biocontrol strengthens natural defences, minimizing the need for artificial fungicides.

Effector-triggered immunity (ETI), on the other hand, is a more specialized response that targets specific pathogen effectors. ETI frequently induces a hypersensitive response (HR), a type of localized cell death that inhibits pathogen development by destroying infected cells. While it was previously thought that PTI and ETI were independent, recent studies show that they work together to create a robust defense system (Tena, 2021). The activation of ETI actually enhances the PTI response, resulting in a strong, multi-layered defence. While ETI alone cannot completely eliminate a pathogen, its capacity to increase PTI assures a more durable immune response, revealing the dynamic and co-evolutionary character of plant-pathogen interactions.

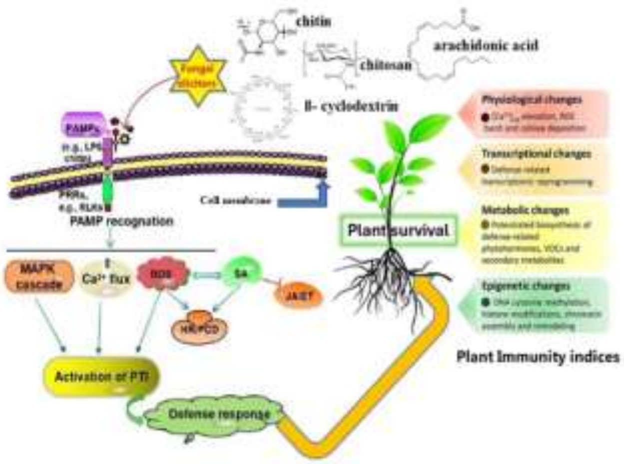

Figure 2 Fungal elicitors activate PTI by inducing stress-responsive genes as well as hormonal cross-talk and prime the plants under stress

5. Conclusion

Advancing research into the use of elicitor molecules in plant protection is extremely important and holds great potential for sustainable agriculture. Elicitor molecules, which activate a plant's inherent defense systems against pests and diseases, provide an environmentally acceptable alternative to conventional chemical pesticides. Their implementation has the potential to decrease environmental impact, limit pest resistance threats, and increase biodiversity. To maintain sustainable and resilient agricultural systems, future research on fungal elicitors should focus on deciphering their molecular mechanisms, optimizing their administration and incorporating them into comprehensive pest management programs. This article focuses on the use of elicitors to bring appropriate attention to the future research necessary in the coming age.

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The Role of Agricultural Extension Services in Enhancing Farmer Livelihoods

Neeraj Kumar, Kajal Kumari , Kumari Krishna Rani
M.Sc. Scholar , Department of Extension Education,
Bihar Agricultural University, Sabour, Bhagalpur, Bihar

Agricultural extension services are instrumental in improving farmer livelihoods, particularly in regions where agriculture remains the primary source of income. This article explores how extension systems bridge the gap between research and practice by equipping farmers with scientific knowledge, sustainable techniques, and modern technologies. It highlights the key contributions of extension services in enhancing productivity, promoting environmental sustainability, building climate resilience, improving market access, strengthening financial literacy, and supporting value-added agri-enterprises. Furthermore, the article examines the role of digital tools, public-private partnerships, and institutional capacity-building in expanding the reach and effectiveness of extension programs. By focusing on these strategic areas, extension services empower farmers to adopt informed, resource-efficient, and market-responsive approaches to agriculture. The article argues that a robust, inclusive, and technologically enabled extension framework is vital for advancing rural development, economic resilience, and food security. Strengthening and innovating within these systems will be essential for transforming agricultural practices and uplifting the livelihoods of millions of smallholder farmers.

Introduction

Agriculture remains the backbone of many economies, particularly in developing countries, where a substantial portion of the population relies on farming for their livelihood. However, traditional practices, limited access to information, inadequate infrastructure, and weak market linkages often restrict farmers from achieving their full potential. In this context, agricultural extension services play a crucial role in addressing these challenges and serve as a powerful means of improving farmer livelihoods.

These services help bridge the gap between scientific research and on-ground farming practices, enabling farmers to adopt improved methods, use resources more efficiently, and enhance their income sustainability.

Defining Agricultural Extension Services

Agricultural extension refers to the organized effort of educating, advising, and supporting farmers with up-to-date information, technical skills, and practical know-how to improve their agricultural operations. This is delivered through:

- Government bodies (e.g., Krishi Vigyan Kendras, ATMA)
- Non-Governmental Organizations (NGOs)
- Private sector players (agribusinesses, agri-tech startups)
- Farmer groups and cooperatives

Extension services cover a wide range of areas, including crop management, livestock care, post-harvest handling, market access, financial literacy, and climate resilience.

Key Strategies For Improving Farmer Livelihoods

1. Enhancing Agricultural Productivity

a. Training and Skill Development

Extension agents conduct field demonstrations, capacity-building workshops, and exposure visits to educate farmers on:

- Scientific farming techniques
- Soil and nutrient management
- Integrated pest and disease control
- Efficient irrigation practices

By applying these practices, farmers can increase yields, reduce losses, and produce higher-quality

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crops—leading to better returns and more stable livelihoods.

b. Access to Improved Inputs and Technologies

Farmers are connected with sources of:

- High-yielding seeds and planting materials
- Bio-fertilizers and advanced farm machinery
- Precision agriculture tools (e.g., drones, sensors)

This allows them to boost production and reduce input costs, creating a more profitable and resilient farming system.

2. Promoting Sustainable Agricultural Practices

a. Environmental and Resource Sustainability

Extension services promote environmentally friendly approaches such as:

- Organic and natural farming
- Integrated Pest Management (IPM)
- Soil health improvement through composting and green manuring

These practices lower chemical use, conserve resources, and maintain ecological balance—improving both farm productivity and long-term sustainability.

b. Climate Resilient Agriculture

As climate patterns become more unpredictable,, farmers are trained in:

- Crop diversification
- Drought- and flood-tolerant varieties
- Water harvesting and conservation methods

This ensures that livelihoods remain secure, even during climate-induced shocks.

3. Facilitating Market Access and Better Returns

a. Access to Reliable Market Information

Extension services help farmers become market-savvy by providing:

- Timely price updates via mobile platforms and bulletins
- Advice on crop choices based on market demand
- Training on grading, packaging, and certification

This empowers farmers to make informed decisions and fetch better prices for their produce, thus improving their livelihood security.

b. Support Through Farmer Collectives

Farmers are organized into:

- Self-Help Groups (SHGs)
- Farmer Producer Organizations (FPOs)
- Cooperative societies

These collectives give farmers stronger negotiating power, reduce dependence on middlemen, and open new market opportunities.

4. Enhancing Financial Literacy and Credit Access

a. Building Financial Skills

Extension programs often include sessions on:

- Budgeting and cost-benefit analysis
- Saving schemes and insurance awareness
- Risk reduction strategies

With better financial literacy, farmers can manage their resources effectively and make informed decisions, leading to more secure and productive livelihoods.

b. Linking to Credit and Insurance

Extension services help connect farmers with:

- Agricultural credit institutions
- Government subsidy programs
- Crop insurance and weather-based insurance products

This financial support enables farmers to invest in better inputs, expand operations, and protect themselves from unforeseen losses.

5. Promoting Value Addition and Agri-Enterprises

a. Reducing Post-Harvest Losses

Extension agents train farmers in:

- Improved storage and transportation
- Processing, grading, and packaging
- Use of cold chains and value chains

Minimizing post-harvest losses means farmers retain more of their hard-earned produce, directly boosting their income and quality of life.

b. Supporting Agribusiness Ventures

Farmers are encouraged to diversify into:

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- Food processing units (e.g., pickles, jams, flour)
- Allied activities like dairy, poultry, beekeeping.
- Organic product marketing and agritourism

These diversified income sources help reduce reliance on seasonal farming and create sustainable livelihood opportunities year-round.

Government Support For Agricultural Extension

Recognizing the pivotal role of agricultural extension services in improving farmer livelihoods and strengthening the agricultural economy, governments at both national and state levels are increasingly prioritizing investments in extension systems. These efforts aim to modernize delivery mechanisms, enhance outreach, and improve the quality and responsiveness of advisory services to meet the evolving needs of farmers. The key areas of government support include digital innovations, strategic partnerships, and capacity development of extension personnel.

Digital and Mobile-Based Advisory Services

The integration of digital technology into agricultural extension has revolutionized the way farmers access critical information. Mobile applications and web-based platforms such as *Kisan Suvidha*, *Pusa Krishi*, and *IFFCO Kisan* serve as comprehensive advisory tools for farmers. These platforms offer a range of real-time services, including:

- **Weather forecasts** to assist farmers in planning agricultural operations such as sowing, irrigation, and harvesting;
- **Market price updates** to help them decide where and when to sell their produce for maximum profit; and
- **Customized agronomic recommendations** tailored to local conditions, soil type, crop variety, and stage of growth.

By providing instant access to relevant and localized information, these digital tools enhance farmers' decision-making abilities, reduce dependency on informal sources, and contribute to increased productivity and profitability.

Public-Private Partnerships (PPPs)

To extend the reach and impact of agricultural extension, governments are actively fostering partnerships with private agri-tech companies, input suppliers, non-governmental organizations (NGOs), and community-based institutions. These collaborations bring in technical expertise, innovative communication tools, and scalable delivery models that complement government efforts.

Noteworthy examples include:

- **Digital Green**, which leverages participatory video-based learning to educate smallholder farmers. These videos are produced locally and feature community members, making the content relatable and easier to adopt.
- **Reliance Foundation Information Services**, which provides a suite of digital and voice-based advisory services to millions of farmers across the country, offering localized information on farming practices, pest management, weather alerts, and government schemes.

Such partnerships not only improve the efficiency of extension services but also promote inclusive access, especially for women farmers and marginal communities

Capacity Building for Extension Workers

A competent and well-equipped extension workforce is central to the effectiveness of any extension system. In recognition of this, governments are making concerted efforts to strengthen the capacities of extension personnel through:

- **Structured training programs** focused on modern agricultural techniques, climate-smart practices, and ICT-based extension tools;
- **Certification systems** that ensure standardization and professional credibility;
- Provision of digital devices, mobility support (such as motorcycles or transport allowances), and communication materials to enhance field operations and outreach; and

- **Establishment of monitoring and evaluation mechanisms** to track the performance, feedback, and impact of extension activities on farmer outcomes.

These initiatives aim to create a dynamic and responsive extension workforce capable of delivering timely, accurate, and actionable information to farmers, thereby bridging the knowledge gap between research institutions and grassroots-level practitioners.

Conclusion

Agricultural extension services are an essential component of rural development. They empower farmers not just to grow more, but to grow smarter, manage risks, and access better opportunities. By improving productivity, sustainability, market linkages, and financial capacity, extension services play a central role in enhancing the overall livelihoods of farming communities.

As governments and institutions continue to invest in and innovate within extension systems—especially through digital platforms and inclusive partnerships—their potential to transform rural economies and uplift millions of farmers becomes even more significant. Strengthening these services is essential for achieving inclusive growth, rural prosperity, and long-term food and economic security.

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Evaluating the Prospects of Jute-Agro Textiles in Mulching Application

Md Selim[1] , Somnath Pati[2]
[1]Department of Agricultural Chemistry & Soil Science
[2]Department of Soil & Water Conservation
Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal

Jute agro textiles provide an environmentally friendly and economical substitute for synthetic materials used in agricultural mulching. As the global agricultural sector moves towards sustainable methods, natural Fiber products such as jute are becoming increasingly important. This article examines the characteristics, advantages, drawbacks, and future possibilities of jute agro textiles in mulching applications, especially regarding their effects on soil health, moisture retention, weed control, and crop yield. The review also emphasizes current research, case studies, and suggestions for encouraging the broader adoption of jute mulch across various agro-climatic regions.

1. Introduction

The agricultural industry faces increasing pressure to implement sustainable practices that harmonize productivity with environmental care. One notable practice that is gaining traction is mulching, which involves placing a protective layer of material, whether organic or inorganic, on the soil surface. Mulching aids in retaining soil moisture, regulating temperature, suppressing weeds, and minimizing erosion, all of which enhance crop performance and soil health. Historically, synthetic plastic mulches have been commonly utilized due to their efficiency and cost-effectiveness. However, their non-biodegradable characteristics present serious environmental challenges, such as soil and water pollution from microplastic contamination and disposal issues. These concerns have led to a shift in attention towards eco-friendly and biodegradable alternatives that can provide similar agronomic advantages without causing long-term ecological damage. Among these sustainable options, natural fiber-based materials like jute agro textiles have surfaced as promising candidates. These alternatives are in line with the objectives of climate-resilient and organic farming, while also bolstering rural economies through the use of renewable resources

2. What Are Jute Agro Textiles?

2.1 Definition and Composition

Jute agro textiles are materials made from jute Fibers that are fabric-based, intended for a range of agricultural applications such as soil conservation, erosion control, seed germination assistance, and mulching. These textiles can be either woven or non-woven and come in different thicknesses and designs to fulfil agronomic needs.

2.2 Properties of Jute

Biodegradability: Naturally breaks down within 6 to 12 months without causing environmental harm. Water Absorption: Effectively absorbs and retains moisture in the soil. UV Resistance: Provides moderate protection against ultraviolet rays, making it appropriate for short-term use in the field. Mechanical Strength: Endures field handling and resists tearing when subjected to moderate mechanical stress. Nutrient Enrichment: Contributes organic matter to the soil as it decomposes.

3. Mulching: Importance and Conventional Practices

3.1 Benefits of Mulching

Mulching offers numerous essential advantages that improve soil health and boost crop productivity. It significantly aids in retaining soil moisture by minimizing evaporation and ensuring stable moisture levels, which is particularly important during dry periods. Weed management is facilitated by obstructing sunlight, which hinders the germination of weed seeds. Furthermore, temperature regulation helps to avert both heat stress and frost damage by maintaining a consistent soil temperature. Moreover, mulching provides control against soil erosion, safeguarding the soil surface from the effects of rain and wind. Over time, organic mulches such as jute enhance soil structure by encouraging humus development and fostering beneficial microbial activity

3.2 Issues with Conventional Plastic Mulches

Traditional plastic mulches are effective for controlling weeds and retaining moisture, but they pose serious environmental and practical challenges. Their inability to biodegrade results in long-lasting accumulation in the soil, which contributes to microplastic pollution that negatively impacts soil health and microbial diversity. After each growing season, disposal issues arise, often leading to practices like burning or landfilling, which further harm the environment. Moreover, plastic mulches do not enhance soil quality and can obstruct water infiltration if not managed correctly. The high costs associated with their removal and the labour-intensive nature of their handling make them less ideal for small-scale or sustainable agricultural practices. These limitations have led to an increased interest in eco-friendly, biodegradable alternatives.

4 Jute Agro Textiles as Mulching Material

4.1 Mechanism of Action

Jute agro textile mulch operates by creating a protective barrier over the soil surface, significantly reducing sunlight exposure and water loss through evaporation. This layer aids in retaining soil moisture, which is particularly vital during dry spells. Its fibrous and porous nature facilitates air and gas exchange, promoting root respiration and the activity of soil microbes. As time passes, jute naturally decomposes, releasing organic matter and nutrients that enrich the soil, enhance its structure, and boost fertility. This slow decomposition process contributes humus, which increases water retention and microbial life, thereby supporting long-term soil health. Additionally, it aids in weed suppression by physically obstructing their growth and emergence.

4.2 Application Techniques

Jute agro textiles can be utilized through various methods tailored to different agricultural settings. Direct mulching involves positioning jute sheets around individual plants or along crop rows to retain moisture and inhibit weeds. Sheet mulching employs larger stitched jute blankets, which are perfect for vast fields or sloped terrains susceptible to erosion. These blankets offer extensive coverage and help stabilize the soil. When combined with organic mulches such as straw, leaves, or compost, the effectiveness can be enhanced, improving moisture retention and nutrient levels. This approach is particularly beneficial in organic farming, as it enhances biodegradability and overall performance. Ensuring proper anchoring and placement is crucial for maintaining the effectiveness of the jute mulch throughout the growing season.

5. Benefits of Jute Mulching

5.1 Environmental Advantages

Jute mulching is environmentally friendly, biodegradable, and compostable, leaving no harmful residues. It naturally decomposes within months, enriching the soil with organic matter. Unlike plastic, it does not contribute to microplastic pollution and promotes sustainable agriculture. Jute also lowers carbon emissions by encouraging renewable resource utilization and reducing environmental harm from synthetic waste.

5.2 Agronomic Benefits

Jute mulch retains soil moisture, inhibits weed growth, and regulates soil temperature, enhancing crop health and productivity. Its porous nature improves aeration and root growth. As it decomposes, it adds nutrients and organic carbon to the soil. Additionally, it aids in erosion control and fosters microbial activity for sustained soil fertility.

5.3 Economic and Social Benefits

Jute mulching enhances rural job opportunities by bolstering jute farming and processing sectors. It provides a cost-effective substitute for synthetic mulches, particularly for small-scale farmers. Being locally sourced, it decreases reliance on imports. Its adoption promotes sustainable livelihoods, aligns with organic farming practices, and strengthens the bio-economy through value chains based on natural resources.

6. Limitations and Challenges

6.1 Durability

Jute mulch generally decomposes within 6 to 12 months, which limits its application in long-term or perennial crops. While advantageous for seasonal crops, its shorter lifespan necessitates regular replacement. Moisture and microbial activity can hasten degradation, presenting challenges in humid climates. Improving durability is a crucial focus for product development and research

6.2 Handling and Storage

Jute mulches are heavier and bulkier compared to plastic, which makes their transport and application in the field more labor-intensive. They need to be kept in dry, well-ventilated areas to avoid premature degradation caused by moisture or pests. If they are exposed to rain or damp conditions during storage, their effectiveness may diminish, complicating logistics, particularly for large-scale farming operations.

6.3 Market Availability

Although there is an increasing interest in jute mulching materials, they are not readily available in all regions. Limited awareness among farmers and poorly developed supply chains impede their adoption. The lack of large-scale commercial production limits both accessibility and affordability. To enhance usage, it is crucial to invest in manufacturing, awareness initiatives, and government support to foster market growth.

7. Scientific Studies and Case Evidence

7.1 India

Investigations in West Bengal and Assam have demonstrated that jute mulch can improve moisture retention by up to 30%, lower weed counts by 40–60%, and increase crop yields in okra, brinjal, and maize by 10–20%. The Jute Research Institute in Kolkata has spearheaded projects focused on erosion control using jute geo-textiles, achieving promising results.

7.2 Europe and North America

In the vineyard and orchard systems of France and Canada, jute mats have been utilized to replace traditional plastic mulch. The outcomes included enhanced soil aeration, increased microbial activity, and yields that are on par with lower long-term costs.

7.3 Africa

Pilot projects in Ethiopia and Kenya have implemented jute textile mulch in vegetable gardens, resulting in improved water-use efficiency and a decrease in the frequency of irrigation.

9. Policy Support and Future Outlook

9.1 Government Initiatives

The Indian government, through organizations such as the National Jute Board (NJB) and the Indian Jute Industries’ Research Association (IJIRA), is actively promoting jute agro textiles to support sustainable farming practices. Various subsidy programs and pilot initiatives have been introduced to incorporate jute mulching into organic and climate-resilient agricultural methods. Programs like the National Mission on Sustainable Agriculture (NMSA) and Paramparagat Krishi Vikas Yojana (PKVY) encourage the use of natural Fibers, including jute, with the goal of decreasing reliance on plastics and enhancing soil health in a sustainable manner.

9.2 International Recognition

Jute agro textiles are increasingly being recognized on the international stage as effective alternatives to plastic mulches in sustainable agricultural practices. Institutions such as the FAO and UNEP advocate for biodegradable options to mitigate environmental pollution and enhance soil health. The potential of

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jute aligns with global climate action objectives, sustainable development initiatives, and circular economy frameworks. Numerous international partnerships and research projects have acknowledged the significance of jute in soil conservation, promoting its application in organic farming, erosion control, and in regions susceptible to drought across Asia, Africa, and Latin America.

9.3 Industry Potential

The jute agro textile sector presents significant growth opportunities in light of the increasing demand for environmentally friendly agricultural inputs. As the focus on sustainable farming, organic certification, and alternatives to plastic intensifies, jute-based mulching products are well-positioned to capture a larger market share. Local production can invigorate rural economies, create job opportunities, and enhance the value of jute crops. Advancements in jute-polymer composites, enhanced durability, and collaborations between government and industry can further boost production levels. Additionally, there are export prospects in the global organic farming and landscape management markets that are in search of biodegradable solutions.

10. Recommendations for Promoting Jute Mulching

To encourage the use of jute mulching, a comprehensive strategy is necessary. Awareness initiatives should be implemented to inform farmers about the environmental and agronomic advantages of jute mulch, especially its biodegradability, moisture retention, and weed control properties. Government assistance through subsidies, participation in sustainable agriculture programs, and demonstration projects can facilitate adoption, particularly among small and marginal farmers. Research and development should concentrate on enhancing the durability and cost-effectiveness of jute agro textiles to accommodate various climatic conditions and crop systems. Strengthening supply chains and promoting local production units will improve availability and lower costs. Public-private partnerships can significantly contribute to expanding manufacturing and marketing efforts. Incorporating jute mulching into organic and climate-resilient farming practices will further enhance its significance. Lastly, policy support, including procurement incentives and quality certification standards, can aid in establishing jute mulch as a standard agricultural input, promoting both sustainability and rural economic growth.

Conclusion

Jute agro textiles present considerable potential for mulching as agriculture transitions towards sustainable methods. With their remarkable moisture retention, biodegradability, and ability to suppress weeds, jute mulch serves as an eco-friendly and cost-effective substitute for synthetic options. Although there are ongoing challenges regarding durability and market acceptance, enhanced policy backing, increased farmer awareness, and continuous research may elevate jute agro textiles to a fundamental component of sustainable farming. Considering climate change, resource conservation, and rural development, the adoption of jute-based mulching systems can play a vital role in promoting resilient and regenerative agricultural practices, enhancing both productivity and environmental responsibility.

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Soil and Water Conservation: Approaches, Methods, and Effects on Sustainable Agriculture

Somnath Pati[1] , Md Selim[2]
[1]Department of Soil & Water Conservation
[2]Department of Agricultural Chemistry & Soil Science
Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal

Soil and water conservation (SWC) plays a crucial role in maintaining agricultural productivity in the face of land degradation, climate change, and water scarcity. This review explores essential SWC strategies—mechanical (such as contour bunding and check dams), biological (including agroforestry and vegetative barriers), and agronomic (like crop rotation and conservation tillage)—adapted to different agro-ecological zones. It underscores the importance of combining in-situ and ex-situ practices, such as mulching and farm ponds, to enhance soil moisture and crop yields. The review assesses the significance of integrated watershed management and policies like PMKSY and MGNREGA. It also identifies challenges such as technical gaps and proposes future research directions in climate-resilient techniques, remote sensing, and ecosystem valuation.

1.Introduction

Soil and water are the two most vital natural resources that constitute the foundation of global agricultural systems. Together they ensure food security, support rural livelihoods, and maintain ecological balance. Healthy soils deliver crucial nutrients, facilitate root development, and uphold the structure necessary for plant growth. Nevertheless, land degradation—evidenced by erosion, nutrient depletion, salinization, compaction, and loss of organic matter—poses a significant threat to sustainable agriculture. Each year, approximately 24 billion tons of fertile soil are lost globally due to erosion, which severely impacts productivity. Water scarcity represents another urgent issue, driven by excessive groundwater extraction, unpredictable rainfall patterns caused by climate change, and inefficient irrigation practices. These challenges are intensified by a lack of awareness, poor policy enforcement, and insufficient integrated planning—especially in rainfed and marginal farming regions. Effective management of these resources is crucial. Soil and water conservation (SWC) includes a variety of practices—mechanical (such as terracing and check dams), agronomic (like mulching and crop rotation), and biological (including agroforestry and vegetative barriers). Integrated watershed management has also shown effectiveness by merging these techniques with community participation. This review aims to: (1) investigate SWC strategies and their scientific foundations; (2) evaluate their effectiveness across different agro-climatic zones; (3) analyse supportive policies and institutions; and (4) identify challenges and suggest research directions for integrated, resilient management of soil and water resources.

2. Causes and Impacts of Soil and Water Degradation

Soil erosion denotes the loss of the nutrient-rich topsoil layer, influenced by water, wind, and human activities such as deforestation, overgrazing, and unsustainable land use practices. It can take several forms—sheet, rill, gully, and wind erosion—each of which degrades soil structure and fertility in different manners. The effects include the loss of essential nutrients, a reduction in soil productivity, sedimentation in aquatic systems, and lower agricultural output. Globally, billions of tons of soil are lost each year, jeopardizing food security and sustainable development. In India, over 45% of degraded land suffers from erosion, particularly in rainfed regions. Preventing erosion through conservation strategies is essential for maintaining soil health and ensuring sustainable agricultural practices.

2.1 Water Erosion

Water erosion progresses through several stages. Splash erosion, which contributes approximately 0.5–1% of soil loss, initiates when raindrops strike exposed soil, dislodging particles and compromising the surface structure. Sheet erosion, accounting for 20–25%, involves the uniform removal of topsoil due to unchanneled surface runoff, leading to a decrease in nutrient availability. Rill erosion, responsible for 25–30%, creates small channels on sloped terrain that can deepen if left unmanaged. Gully erosion, the most damaging type, results in 40–45% of soil loss by carving deep channels into the landscape, particularly in regions with heavy rainfall and limited vegetation. This often makes the land unsuitable for cultivation without significant structural restoration.

2.2 Wind Erosion

Wind erosion operates through three main mechanisms. Surface creep, which accounts for 5–10% of soil loss, occurs when larger soil particles (0.5–2 mm) roll or slide across the ground. Saltation, the most prominent process (50–70%), involves medium-sized particles (0.1–0.5 mm) that bounce and dislodge other particles upon impact. Suspension, responsible for 20–40%, elevates fine particles (<0.1 mm) into the atmosphere, leading to dust storms that diminish soil fertility and impair air quality. Wind erosion is especially pronounced in arid and semi-arid areas characterized by dry, loose soil and minimal vegetation cover.

3. Global and Area-Specific Data Concerning Erosion

Globally, soil erosion impacts nearly 75 billion tons of soil annually, greatly reducing agricultural productivity and jeopardizing food systems. The FAO estimates that one-third of the world's soils are degraded, with erosion being the leading factor. On arable land, erosion rates typically fall between 10 and 20 tons per hectare each year, and can surpass 100 tons per hectare in at-risk areas. In India, approximately 147 million hectares are affected by degradation, primarily due to water erosion. Sub-Saharan Africa experiences erosion on roughly 65% of its agricultural land, driven by deforestation, overgrazing, and poor land management practices.

3.1 Water Scarcity: Diminishing Groundwater, Irregular Rainfall, and Excessive Irrigation Application

Water scarcity, an escalating threat to agriculture and human existence, results from excessive groundwater extraction, unpredictable rainfall patterns caused by climate change, and inefficient irrigation methods. In Indian states such as Punjab and Haryana, the overuse of tube wells has significantly reduced aquifer levels. Irregular monsoons impede natural recharge and elevate drought risks. Practices like flood irrigation contribute to water wastage and soil salinization. Implementing solutions like rainwater harvesting, drip irrigation, and sustainable water policies is crucial for tackling this crisis.

3.2 The Impact of Climate Change

Climate change exacerbates water scarcity by interfering with the water cycle. Rising temperatures heighten evaporation, leading to decreased surface water in rivers and lakes. Changed rainfall patterns and prolonged droughts affect both water quantity and quality. Glacial melting results in temporary increases but ultimately leads to shortages. The rise in sea levels causes saltwater to intrude into coastal aquifers. These consequences reduce water availability for agriculture, drinking, and ecosystems, underscoring the critical need for climate-resilient water management strategies.

4. Consequences for Agriculture

4.1 Decline in Fertility and Yield Reduction

Soil erosion and water scarcity have a significant impact on agriculture, leading to reduced soil fertility and crop yields. Erosion removes nutrient-rich topsoil, which weakens the soil structure and decreases productivity. Water scarcity, which is caused by the depletion of groundwater and irregular rainfall, limits irrigation and hinders plant growth. These challenges result in lower yields, diminished crop quality, and increased input costs, making

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marginal lands less productive. This threatens food security and the livelihoods of farmers. Adopting sustainable practices is essential for restoring soil health and ensuring long-term agricultural productivity in the face of changing environmental conditions.

4.2 Waterlogging, Salinization, And crop failure

Waterlogging and salinization pose significant risks to sustainable agriculture, leading to serious crop failures. Waterlogging decreases oxygen levels in the root zone, which impairs root respiration and plant development, particularly in crops such as wheat and pulses. Salinization occurs due to inadequate irrigation and drainage, frequently found in arid areas, where the accumulation of salt interferes with water and nutrient absorption, rendering the soil toxic.

5. Soil Conservation Measures

5.1 Mechanical Methods

5.1.1 Contour Bunding

Earthen embankments built along contour lines help reduce runoff and erosion. These structures divide land into sections, improve moisture retention, and suit dryland areas with uneven terrain, boosting crop productivity.

5.1.2 Terracing

This converts steep slopes into flat steps that slow water flow and increase infiltration. It is common in hilly regions and helps prevent erosion and landslides, while expanding usable farmland.

5.1.3 Check Dams

Small barriers across streams or gullies reduce water speed, trap sediments, and recharge groundwater. Effective in semi-arid areas, they support drought resilience and soil moisture.

5.2 Agronomic Measures

5.2.1 Strip Cropping

Erosion-prone crops are alternated with resistant ones like legumes. This practice reduces runoff, increases infiltration, and stabilizes the soil.

5.2.2 **Crop Rotation**

Alternating crops preserves soil fertility and disrupts pest cycles. Legumes in the cycle enhance nitrogen levels, cutting reliance on fertilizers.

5.2.3 Cover Cropping

Planting during fallow periods maintains soil cover, improves organic content, and boosts microbial activity and fertility.

5.2.4 Conservation Tillage

This practice limits soil disturbance, preserves residues, improves structure, reduces erosion, and conserves moisture.

5.3 Biological Measures

5.3.1 Vegetative Barriers

Grasses like vetiver and lemon grass planted along contours bind the soil, reduce runoff, and trap sediment. They are eco-friendly and low-cost, ideal for sloped or degraded land.

5.3.2 Agroforestry

Trees and shrubs integrated with crops/livestock improve soil stability, nutrient recycling, and productivity. It offers fuel, fodder, and ecological balance.

5.3.3 Windbreaks and Shelterbelts

Rows of trees reduce wind speed and erosion. Common in dry regions, they protect crops, retain moisture, and improve microclimates.

6. Water Conservation Techniques

6.1 In-Situ Moisture Conservation

6.1.1 Ridge and Furrow System

Raised ridges and sunken furrows capture rainwater, improving root-zone moisture. Suitable for row crops and sloped land.

6.1.2 Mulching

Organic or synthetic covers like straw or plastic reduce evaporation, suppress weeds, and stabilize soil temperature, enhancing yields and water efficiency.

6.1.3 Deep Ploughing

Breaking compacted subsoil increases infiltration and aeration. It benefits hardpan soils and supports crop growth in dry spells.

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6.2 Ex-Situ Water Harvesting

6.2.1 Farm Ponds

These structures collect runoff for use in irrigation and livestock. Properly lined, they reduce groundwater dependence and help during droughts.

6.2.2 Check Dams

These retain runoff in seasonal streams, recharge groundwater, control erosion, and are essential for watershed areas.

6.2.3 Percolation Tanks

Shallow tanks that allow slow infiltration to replenish aquifers. Common in drought-prone zones, they sustain water levels.

6.2.4 Rooftop Rainwater Harvesting

Capturing rooftop rainwater in tanks or recharge pits reduces demand and enhances groundwater, aiding water-scarce rural and urban areas.

7. Integrated Soil and Water Conservation: Watershed Management

7.1 Principles of Watershed Management

Integrates land-use planning with soil and water conservation. It enhances vegetation, reduces runoff, and supports ecological balance and rural development.

7.2 Community Participation and Institutional Support:

Local involvement ensures sustainability and relevance. Support from governments, NGOs, and institutions enables technical and financial inputs and fair governance.

7.3 Role of Remote Sensing and GIS

These tools improve watershed planning by providing data for mapping, monitoring, and targeted interventions.

8. Policy and Institutional Frameworks

8.1 National Watershed Development Programme (NWDPRA)

Launched in 1990, this program promotes sustainable productivity in rainfed areas through participatory watershed management, soil and water conservation, and ecological restoration.

8.2 Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)

Launched in 2015, this integrates irrigation schemes aiming for "Har Khet Ko Pani." It promotes micro-irrigation, reduces wastage, and improves soil and crop productivity.

8.3 MGNREGA and Soil Conservation

Funds rural employment and resource-building activities like trenches, bunds, and check dams, aiding in soil restoration and groundwater recharge.

8.4 Role of ICAR, NABARD, and NGOs

ICAR supports research, NABARD offers funding, and NGOs engage communities in sustainable resource management.

9. Benefits and Challenges of SWC Practices

9.1 Enhanced Water Use Efficiency

Techniques like drip irrigation, mulching, and contour farming increase root-zone moisture and reduce runoff, ensuring sustainable water use.

9.2 Improved Soil Fertility and Productivity

Practices like cover cropping and composting reduce erosion and enhance microbial health, boosting long-term productivity.

9.3 Challenges Funding, Maintenance, Farmer Awareness, Scalability

Barriers include limited funding, lack of maintenance, low farmer awareness, and poor scalability. Addressing these requires capacity building, policy support, and community involvement.

Conclusion

Soil and water conservation is essential for sustainable agriculture in the context of climate change and resource degradation. Integrating mechanical, agronomic, and biological approaches enhances soil structure, improves water retention, and supports long-term productivity and ecological resilience.

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AGRICULTURE BULLETIN
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Goat Milk: A Nutritious and Natural Dairy Alternative

Mukesh Gangwar[1], Sadhana Ojha[1], Shiv Varan Singh[2] and Abhishek Kumar[3]
[1]Department of Livestock Products Technology,
[2]Department of Veterinary Microbiology,
[3]Department of Veterinary Gynaecology and Obstetrics,
College of Veterinary and Animal Sciences (BASU), Kishanganj, Bihar

1.Introduction

Milk has long been a cornerstone of the human diet, valued for its rich nutritional content and essential role in growth, development, and overall health. While cow's milk dominates the global dairy market, goat milk has quietly earned a reputation as a highly nutritious and easily digestible alternative. In many parts of the world, including the Middle East, Africa, and South Asia, goat milk is not only a staple but also a preferred source of dairy, especially in rural and traditional households. Goat milk is known for its unique composition, which makes it more compatible with the human digestive system compared to cow milk. Its smaller fat globules, different protein structure, and slightly lower lactose content contribute to better digestibility, making it a suitable option for individuals with mild lactose intolerance or cow milk sensitivity. Unlike cow milk, goat milk curdles into softer curds in the stomach, which can ease the digestive process and reduce gastrointestinal discomfort.

Beyond digestibility, goat milk is a powerhouse of nutrients. It contains high-quality proteins, essential fatty acids, vitamins like A, B2 (riboflavin), and D, as well as minerals such as calcium, phosphorus, and magnesium. These nutrients support a wide range of physiological functions, including bone health, immune response, skin vitality, and metabolic activity. Interestingly, goat milk contains preformed vitamin A (retinol), which is more bioavailable than the beta-carotene found in cow milk. With the rise in demand for functional foods and natural remedies, goat milk is increasingly recognized for its therapeutic potential. It is being explored in modern research for benefits in conditions such as malabsorption syndromes, allergies, cardiovascular health, and even neurodegenerative diseases. Furthermore, its use extends beyond the kitchen; goat milk is a sought-after ingredient in cosmetic products for its moisturizing and anti-inflammatory properties.

2. Composition of Goat Milk

Goat milk contains essential nutrients that make it a valuable part of the human diet. Its composition is close to human milk, which is one reason it's considered more digestible than cow's milk.

Table. 1: Key Components (approximate values per 100 ml of goat milk):

Component	Quantity
Water	87.0 g
Fat	4.1 g
Protein	3.4 g
Lactose (Milk sugar)	4.4 g
Ash (minerals)	0.8 g
Energy	70 kcal

- **Proteins**: Rich in casein and whey proteins; slightly different in structure from cow's milk, which contributes to better digestibility.
- **Fats**: Contain short- and medium-chain fatty acids like caproic, caprylic, and capric acids that are more readily absorbed.
- **Lactose**: Slightly less than cow's milk, making it easier for some people to tolerate.
- **Vitamins**: Rich in vitamin A, riboflavin (B2), and niacin, but lower in folic acid and vitamin B12 compared to cow milk.

- **Minerals**: High in calcium, phosphorus, potassium, and magnesium.

3. Nutritional Value of Goat Milk

Goat milk is a powerhouse of nutrition, offering various benefits across age groups.

Macronutrients:

- **Protein**: High-quality proteins essential for muscle repair, immune function, and growth. The protein structure forms softer curds, aiding in digestion.
- **Fat**: The smaller fat globules in goat milk require less homogenization and may aid in faster digestion and absorption.
- **Carbohydrates**: The slightly lower lactose content (around 4.4%) makes it better tolerated by people with lactose sensitivity.

Micronutrients:

- **Calcium**: Critical for bone and dental health; goat milk provides about 130 mg/100 ml.
- **Potassium & Magnesium**: Help maintain heart health and regulate blood pressure.
- **Vitamin A**: Present in preformed form (retinol), unlike cow milk, which contains beta-carotene. This contributes to better vision and skin health.
- **Riboflavin (B2)**: Supports energy metabolism.
- **Selenium and Zinc**: Strengthen immunity and play roles in antioxidant defence.

Bioactive Components:

- **Medium Chain Triglycerides (MCTs)**: Boost metabolism, support brain function.
- **Oligosaccharides**: Promote gut health, similar to those found in human breast milk.
- **Conjugated Linoleic Acid (CLA)**: May have anti-inflammatory and anti-cancer properties.

4. Health Benefits of Goat Milk

- **Easy Digestion**
  - Due to smaller fat globules, different protein structure, and the presence of MCTs, goat milk is easier to digest than cow milk. It also causes less bloating and gastrointestinal discomfort.
- **Hypoallergenic Properties**
  - Goat milk contains less αs1-casein protein, a common allergen in cow's milk. Hence, some people allergic to cow milk protein may tolerate goat milk better (though not all).
- **Supports Bone Health**
  - The high calcium and phosphorus content helps in preventing osteoporosis and supports bone development in children and elderly alike.
- **Promotes Healthy Skin**
  - Vitamin A and essential fatty acids in goat milk nourish the skin. It is also used in cosmetic products like soaps and creams.
- **Boosts Immunity**
  - Selenium, zinc, and bioactive peptides present in goat milk play a role in strengthening the immune system.
- **Good for Heart Health**
  - Goat milk's potassium content helps regulate blood pressure, and the presence of healthy fats supports cardiovascular well-being.
- **Beneficial for Lactose-Intolerant People**
  - Although not lactose-free, goat milk's lower lactose content and easier digestibility make it better tolerated by some individuals.

Table. 2: Goat Milk vs Cow Milk: A Comparison

Nutrient/Feature	Goat Milk	Cow Milk
Fat Globule Size	Smaller	Larger
Lactose Content	Slightly Lower	Higher
Protein Allergenicity	Lower	Higher
Vitamin A	Preformed (retinol)	Beta-carotene
Calcium	Slightly Higher	Slightly Lower

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Taste	Strong/Distinct	Mild
B12 & Folic Acid	Lower	Higher
Digestibility	Easier	Moderate

5. Uses of Goat Milk

Goat milk is versatile and used in various forms:

Dairy Products

- **Cheese**: Feta, chèvre, and ricotta made from goat milk are highly popular.
- **Yogurt & Curd**: Creamy texture with probiotic benefits.
- **Butter & Cream**: Used in gourmet cooking.
- **Milk Powder & Infant Formula**: With added nutrients.

Skincare Industry

Used in **soaps, lotions, shampoos**, and **anti-aging creams** due to its moisturizing and anti-inflammatory properties.

Goat Milk in Traditional and Alternative Medicine

In Ayurveda and traditional medicine systems, goat milk is considered **sattvic**—calming, nourishing, and easily digestible. It has been used to:

- Support recovery in tuberculosis
- Improve digestion
- Manage ulcers
- Aid in convalescence

6. Conclusion

Goat milk offers a unique combination of digestibility, nutrition, and health benefits, making it an excellent dairy alternative for many individuals. From supporting gut health to strengthening bones and boosting immunity, its advantages are well-supported by both traditional wisdom and modern science. However, it is not a magic bullet. Individuals with dairy allergies, infants, or those with specific nutrient needs should approach goat milk consumption thoughtfully, ideally under the guidance of a healthcare professional. With proper sourcing and consumption, goat milk can be a wholesome and beneficial addition to a balanced diet.

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Rethinking the Green Revolution in the Era of Climate Change

[1]Dr .Akhil Bharti, [2]Pallavi K. N., [3]Dr. Sudha Darbha, [4]Gouraram Manoj Kumar Goud, [5]Dr. Anil Kumar

[1]Assistant Professor, Faculty of Agriculture, Maharishi Markandeshwar (Deemed to be University) Mullana Ambala Haryana

[2,4]Ph.D. Scholar, Department of Agronomy, College of Agriculture, Rajendranagar, PJTAU, Hyderabad, Telangana

[3]Founder, Orion Consultants, Near NIT Garden, Nagpur (MS)

[5]Assistant Professor, Department of Agronomy, School of Agriculture, Eklavya University Damoh, Madhya Pradesh

The Green Revolution increased world food production and alleviated hunger, but it also resulted in environmental degradation, overutilization of resources, and social inequity. With growing intensification of climate change, these are becoming increasingly acute. This bulletin looks at the Green Revolution legacy and calls for a new agricultural paradigm based on sustainability, resilience, and equity. Key strategies are climate-resilient crops, regenerative agriculture, water-saving practices, and the blending of digital and indigenous knowledge. In order to achieve secure future food systems, we need to shift from extractive to regenerative practices with an emphasis on biodiversity, soil health, and equitable development.

2.Introduction

The Green Revolution is a concept for a time of accelerated agricultural development, which started during the 1940s and peaked during the 1960s and 1980s. It was influenced by scientific breakthroughs, government initiatives, and global cooperation. The revolution brought with it HYVs of staple food crops like wheat and rice, as well as increased application of chemical fertilizers, synthetic pesticides, and intensive irrigation.

Norman Borlaug, sometimes referred to as the "father of the Green Revolution," was instrumental in producing disease-resistant wheat strains that greatly increased production. These technologies proved particularly revolutionary in developing countries such as India and Mexico, where famine and starvation were prevalent threats. Through the modernization of agriculture, the Green Revolution prevented wholesale starvation and set the stage for future economic growth in much of the world. Borlaug, *et.al.* 2002.

The Successes

- More Food: Global production of cereals doubled more than twice between 1950 and 1990, matching the rising population growth.
- Less Hunger: Malnutrition and death due to famine fell extensively throughout much of Asia and Latin America.
- Farming Efficiency: Productivity increases enabled certain nations to produce enough food to feed themselves and lower their import dependence.

Source: https://www.eea.europa.eu

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The Hidden Costs

These were overshadowed, however, by certain unwanted side effects. Environmental degradation was a result of excessive use of chemical fertilizers and pesticides, contaminating the soil and water. Monocropping decreased agricultural diversity and raised vulnerability to pests and disease. Socially, small farmers were frequently unable to pay for the new technology, further entrenching inequalities and generating debt cycles. Such legacy problems are further compounded today by climate change, making it imperative to reimagine the agricultural model we depend upon now. Horlings *et.al.* 2011.

3.The Environmental and Social Legacy

Although the Green Revolution increased food production enormously, it also created a multifaceted legacy of environmental and social impacts that still influence agricultural systems today.

Ecological Impact

- Soil Degradation: The heavy application of chemical fertilizers, along with multiple monoculture plantings of high-yielding varieties, broke natural cycles of soil. Organic matter and beneficial microorganisms fell, lowering soil fertility and long-term yields.
- Water Deficiency: Huge irrigation systems required tremendous amounts of water. In places such as the Indo-Gangetic Plain, excessive groundwater extraction caused water tables to decline at alarming rates. Salinization due to ill management of irrigation made previously fertile land unfertile.
- Biodiversity Loss: The substitution of numerous traditional seed varieties with a few genetically similar hybrids at the farm level significantly diminished farm-level biodiversity. It not only impacted ecological stability but also increased crop susceptibility to pests, diseases, and climatic shocks.
- Chemical Contamination: Excess fertilizers and pesticides runoff polluted rivers, lakes, and groundwater. These contaminants injured aquatic organisms and found their way into food for humans and drinking water, creating health issues and polluting ecosystems.

Social and Economic Problems

Disadvantage of Small Farmers: The Green Revolution benefited large-scale, well-equipped farmers who had access to inputs such as seeds, machinery, and chemicals. Smallholders, due to the inability to maintain these expenses, were left behind, widening economic inequalities.

Debt and Farmer Suicides: Across much of the world, especially in India, farmers have gone into debt to buy costly inputs. When crops have failed through pests, drought, or market crashes, many are left in disastrous debt—accruing increasing levels of farmer suicides.

Gender Gaps: The technological emphasis of the Green Revolution has largely left out women, even though they played a key role in agriculture. Land, credit, and training were normally made available to men, creating gender inequality in rural communities.

4.Climate Change – A New Challenge for Agriculture

The Climate Crisis and Agriculture

Agriculture is at a crossroads today. It is at once one of the world's largest contributors to climate change and one of its earliest and most conspicuous casualties. Food production systems worldwide contribute about 20–25% of greenhouse gas (GHG) emissions. These emissions are mostly due to:

- Methane, emitted by livestock like cows and sheep as they digest food.

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- Nitrous oxide, released from the application of synthetic fertilizers and manure.
- Carbon dioxide, a product of deforestation and land-use alteration, particularly when forests are cut down to make way for farmland.

Ironically, agriculture is itself responsible for warming the planet yet is exceedingly susceptible to its effects. Farmers, especially in the developing world, are already witnessing enhanced unpredictability in weather, changes in seasons, and enhanced frequencies of extreme events — all of which are reducing food security. Kirchner *et.al.* 2023.

Source: https://en.wikipedia.org

Climate Impacts on Farming

Shifting Rainfall Patterns: Climate change is changing rainfall patterns, resulting in more severe and recurrent droughts in some regions and floods in others. The extremes interfere with planting and harvest calendars, cutting yields and enhancing crop failure risk.

- Severe Heat: Increased temperatures lead to heat stress in livestock and crops. Repeated heat waves decrease grain filling in cereals and affect milk and meat production, threatening livelihoods as well as nutrition.
- Pest and Disease Spread: Warmer and wetter conditions are expanding the range of crop pests and diseases. Regions previously unaffected are now facing new threats, requiring more complex pest management strategies.
- Soil Carbon Loss: Land degradation through deforestation and intensive tillage releases stored carbon into the atmosphere. Healthy soils are crucial for climate mitigation, but degraded soils lose their capacity to sequester carbon, creating a dangerous feedback loop.

5. Why We Need a New Green Revolution

Limitations of the Original Model

The initial Green Revolution was undoubtedly a milestone in agricultural history, preventing famine and nourishing increasing populations. But it was meant first of all to increase yields in a post-war era focused on food scarcity—not long-term sustainability. This production focus resulted in extensive use of chemical inputs, intensive monoculture, and irrigation networks that severely stressed natural ecosystems. Santos *et.al.* 2011.

Now, the global situation is different. Climate change, soil erosion, water shortages, and loss of biodiversity now pose a threat to the very base of food systems. The existing system, founded on energy-intensive inputs from fossil fuels and resource extraction, no longer works. We require a new way—one that takes care of increasing numbers of people without compromising the planet's health.

Key Needs Today

- Climate-Resilient Crops: Future agriculture has to ensure crops that are capable of tolerating increasingly unpredictable weather events. This involves developing and distributing drought-, heat-, and flood-tolerant cultivars through conventional breeding as well as by using new biotechnological approaches.
- Agroecology and Regenerative Agriculture: Instead of controlling nature, new farming systems have to cooperate with nature.

Agroecology encourages diversified, low-input agriculture that increases ecosystem services, while regenerative agriculture emphasizes repairing soil health, sequestering carbon, and re-establishing biodiversity.

- Lowered Emissions: The use of sustainable agricultural practices, like better manure management, organic fertilizer, and precision agriculture, can drastically reduce methane and nitrous oxide emissions—two of the most powerful greenhouse gases.
- Food System Equity: Any future agricultural revolution has to be inclusive. Indigenous peoples, women, and smallholder farmers—historically left behind by previous innovations—have to be at the center of future solutions, enjoying land access, technology, education, and decision-making authority.

6. Pathways Toward a Sustainable Agricultural Future

To confront the double challenge of climate change and food security, agriculture has to become an agricultural system that regenerates nature, empowers communities, and nourishes people in a sustainable way. The change needs a mix of innovation, tradition, and inclusive policy. The following routes provide a roadmap for a climate-resilient and smart agricultural future. Pielke *et.al.* 2019.

1. Diversification and Agroecology

Transitioning from monoculture to diverse cropping systems increases ecological harmony and decreases reliance on chemical inputs. Crop diversification enhances vulnerability to pests, disease, and climate change. Agroforestry—integrating trees into agricultural fields—and integrated farm systems that incorporate crops, livestock, and aquaculture may rehabilitate degraded ecosystems, increase biodiversity, and enhance farmers' income streams.

2. Soil Health and Regenerative Practices

Healthy soil is the key to sustainable agriculture. No-till farming, cover cropping, crop rotation, and composting are some of the regenerative practices that increase soil organic matter, microbial life, and water retention capacity. Not only do they restore soil fertility but also sequester atmospheric carbon, thus addressing climate change.

3. Water-Smart Agriculture

Water scarcity is intensifying with climate change. Techniques like precision irrigation, drip systems, and rainwater harvesting ensure efficient water use, particularly in drought-prone areas. Encouraging water-use efficiency can protect freshwater resources while maintaining crop productivity.

4. Digital and Indigenous Knowledge Integration

New technologies like AI, drones, satellite photography, and data analytics can track crop well-being, predict weather, and maximize input use. But complementing them with indigenous and traditional knowledge—grounded in centuries of ecological knowledge—allows for culturally appropriate, locally tailored solutions.

5. Policy and Investment

Supportive policy is necessary. Investments in climate-smart R&D, infrastructure, and extension empower farmers to make the shift. Moreover, fair trade, carbon pricing, and sustainability incentives can connect economic objectives with environmental management.

7. Conclusion – Towards a Just and Climate-Resilient Revolution

The Green Revolution revolutionized world agriculture, sharply boosting food production and saving countless lives from famine. But it was achieved at a high environmental and social price—

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soil erosion, water shortages, loss of biodiversity, and increased disparities. They are no longer secondary concerns; with climate change, they are the core of an escalating crisis.

With the warming of the planet and erratic weather patterns, it is no longer an option to continue depending on antiquated, high-input, industrial agricultural systems. We need to reenvision agriculture not just as calorie production, but as a living system—a system that restores ecosystems, honors traditional knowledge, empowers the poor, and promotes planetary health.

This new revolution in agriculture needs to be led by a profoundly positive vision. It has to put priority on regenerative agriculture

- Soil rejuvenation over chemical inputs, regaining the earth's ability to support life and capture carbon.
- Biodiversity over monoculture, favoring resilience through natural balance.
- Equity over exclusion, making small-scale farmers, women, and Indigenous peoples leaders—not add-ons—to design the future of food.
- Long-term resilience over short-term yield, investing in systems that are climate-resilient and support future generations.

Building a climate-resilient food system is not merely a technical task—it's a matter of justice. It calls for international solidarity, ambitious policy changes, and profound respect for both science and indigenous knowledge.

The future of food, and that of life on our planet, hinges on our ability to draw from the past while fearlessly seeking new directions—ones that feed people and sustain the earth.

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Role of endophytes in plant defense mechanism

Patel Payal R.[1] and Rakholiya K. B.[2]

[1]Patel Payal R., Junior Research Fellow, Food Quality Testing Laboratory, Navsari Agricultural University, Navsari

[2]Rakholiya K. B., Professor and Head (I/c), Department of Plant Pathology, N. M. College of Agriculture, Navsari Agricultural University, Navsari

Endophytes are microorganisms residing within plants without causing visible disease symptoms. It has been reported that at least one or more than one endophyte reside in every three lakh plant species that exist on the earth, but only 6%–7% of the endophytes existence has been known. Generally there are three types of endophytes. Endophytic fungi, endophytic bacteria and endophytic actinomycetes. They are predominantly found in -α, β, and γ-proteobacteria being the most diverse. Use of beneficial micro-organisms such as endophyte were taken much attention due to its eco-friendly and cost-effective approach. The biocontrol ability of endophytic microbes is due to the production of vari¬ous bioactive metabolites.

Introduction

Endophyte means microorganisms lives inside the plants. The term endophyte most commonly refers to microorganisms that can be isolated from surface disinfected plant tissues without visible diseased symptoms "Endophytes are microorganisms that spend at least part of their life cycle inside plants". It has been reported that at least one or more than one endophyte reside in every three lakh plant species that exist on the earth, but only 6%–7% of the endophytes existence has been known (Gupta *et al.,* 2019). Endophytic species mostly belong to the -*α, β*, and *γ*-proteobacteria subgroups. Interestingly, the γ-proteobacteria group is the most diverse and dominant. Among all, Fungal endophytes are extremely common and highly diverse micro-organisms that live within plant tissues but usually do not produce symptoms. The most commonly found endophytic bacteria *viz., Acidovorax facilis, Bacillus chitinoporus, Bacillus laterosporus, Bacillus subtilis, Rhizobacteria, Enterobacter sp., Burkholderia cepacia.*

Mechanism

The endophytes interact particularly with pathogens by various ways and these exploited as bio-control agents. They mainly interact through direct and indirect mechanisms such as Competition, mycoparasitism, antibiosis and induced resistance. 1. Mycoparasitism- Fungal endophytes parasitize around hyphae of pathogens by various means as twisting, penetrating the hyphae of pathogens and secreting lyase to decompose cell wall of pathogens.

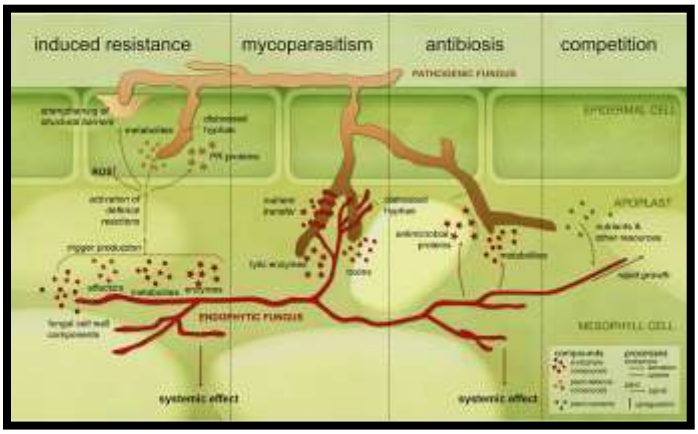

Fig. 1: Mechanisms of plant protection by endophytes (Latz et al., 2018)

2. Competition- It is an important factor in the control of pathogens by endophytic microorganisms, since both organisms colonize similar niche and utilize the same nutrients in the host plant. 3. Antibiosis- It is the ability of an endophytic microorganism to inhibit pathogen growth by the production of antibiotic (Latz *et al.,* 2018). 4. Lytic enzyme production- Many endophytic microorganisms produce and release lytic enzymes that can hydrolyze a wide variety of polymorphic compounds, including chitin, proteins,

cellulose *etc*. For chitinase activity, chitinase detection medium used. Chitinase activity is identified due to the formation purple colored zone.

5. Induction of plant resistance- Some endophytic microorganism indirectly protects plants from pathogens by inducing resistance in plants. Systemic acquired resistance (SAR) and induced systemic resistance (ISR) are two forms of induced resistances.

Case study

Ji *et al.* (2008) evaluated that the strain Lu144 of *Bacillus subtilis* effectively reduced disease incidence of bacterial wilt caused by *R. solanacearum* of mulberry in both sterile and non sterile soil over untreated control. Vetrivelkalai *et al.* (2010) reported that bhendi seeds treated with culture filtrates of EB16 (*Bacillus* sp.), EB18 (*Bacillus* sp.), EB19 (*Methylobacterium* sp.) and EB3 (*Pseudomonas* sp.) significantly reduced the number of adult females, egg masses, eggs/egg mass, root and soil population of *M. incognita* under pot conditions. The lowest root gall index (1.00) was found both in EB16 and EB18 isolates and it was followed by EB19 and EB3 (1.33) compared to untreated control (4.67). Thangavelu and Gopi (2015) enumerated that the soil application of endophytic and rhizospheric bacterial isolate (Endo. *Bacillus flexus* + rhizo. *Bacillus cereus*) combinations significantly reduced (57.8 to 72%) Fusarium wilt in *cv.* Grand Naine when compared to untreated control plants. Sarirekha and Srividya (2016) were tested *in vitro* antagonistic activity of the strain *Pseudomonas aeruginosa* FP6 against *R. solani* and *C. gloeosporioides*. It showed a significant reduction in *R. solani* growth with $FeCl_3$ compared to the control (without $FeCl_3$). Jayakumar *et al.* (2018) tested four endophytes for biocontrol potential in field under artificially pathogen inoculated condition. Results showed that they all are effective in suppression of smut disease. The least smut incidence (14.8%) was recorded by ESR7 (endophytic bacteria) treated setts followed by ESR 21 when compared to control. Hamzah *et al.* (2018) conducted *in vitro* antagonism of six selected endophytic fungal isolates against the pathogenic fungus *F. solani* using two types of assays. Among them, by Dual culture assay *Phoma* sp. recorded the highest inhibition per cent growth over control. By non-volatile compound assay, *xylaria sp.* recorded the highest inhibition per cent growth over control. Zanudin *et al.* (2020) tested antagonistic activities of all endophytic fungi against *C. gleosporioides* pathogen from different plant parts of *Garcinia atroviridis* by dual culture assay and revealed that all endophyte isolates showed >50% inhibitory activity against pathogen. Rajani *et al.* (2021) concluded that, growth of three of the pathogenic fungi *viz., S. sclerotiorum-TSS, S. rolfsii- CSR* and *F. oxysporum-CFO* were significantly inhibited by all four endophytes in double plate assay. The inhibition percentage ranged between 40 and 65 across the endophyte-pathogen pairs. None of the four endophytes inhibited *M. phaseolina -CMP* in the double plate assay.

Conclusion

From the foregoing discussion, it can be concluded that various fungal endophytes (*Trichoderma* sp.) and bacterial endophytes (*Pseudomonas* sp., *Bacillus* sp.) are significantly able to control the plant pathogens. Most plants are colonized by a broad spectrum of endophytic bacteria and fungi that are potentially antagonistic towards fungal, bacterial and nematode plant pathogen. They also noted that the major benefit of embracing such beneficial microorganisms in the field of agriculture is to bring about reduction in the use of different agrochemicals such as pesticides, chemical fertilizers and this would make agriculture more productive and sustainable. The use of endophytic fungi for the plant disease control is relatively new and unexplored area of research.

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Cold Plasma in Postharvest: A Gentle Revolution in Food Safety and Quality

L. Harithraadevi, PG Scholar,
Dr. A. Beaulah, Professor and Head
Department of Post Harvest Technology,
Horticultural College and Research Institute, TNAU, Periyakulam, Theni.

Foodborne illnesses caused by microbial contamination are a major public health concern, leading to millions of infections and significant economic losses worldwide. Addressing this issue requires innovative, effective, and safe decontamination methods. Cold plasma is a non-thermal, emerging technology that offers great potential to improve food safety and shelf life without compromising product quality. It is a partially ionised gas composed of reactive species. It works well at room temperature, making it safe for use on fresh fruits, vegetables, meat, milk, and juices without changing their taste, texture, or nutrients. It can also reduce browning and increase beneficial compounds like antioxidants. In packaging, it helps improve the material's ability to block air and moisture. Although the technology shows great results in the lab, more research is needed to understand its full effects on food and to make it suitable for large-scale use. With further development, cold plasma could become an important tool for safe, clean, and eco-friendly food processing.

Introduction

Foodborne illness due to contaminated food has been increasing nowadays. Decontamination continues to be a primary focus in modern food research, aimed at enhancing food safety, prolonging shelf life, and effectively reducing microbial risks across the entire supply chain. Minimising microbial contamination in fresh produce and food products has emerged as a critical priority in the food processing industry to prevent spoilage and significantly reduce the risk of foodborne illnesses. Foodborne diseases are caused by microorganisms like *E. coli*, *Listeria monocytogenes*, *Salmonella*, etc. Ensuring food safety and quality relies on postharvest technology to preserve food integrity from harvest to consumption. Cold plasma is an emerging, non-thermal, and green technology used in the postharvest sector to improve food safety and shelf life without compromising quality. Let's discover how cold plasma technology is changing the way we keep food fresh and safe.

What is plasma?

The term "plasma" was introduced by Irving Langmuir in 1928, who identified and described it as the fourth state of matter. It is composed of energetic species which include ions, electrons, atoms, excited molecules and charged particles. It often appears as a bright fluorescent glow or electric arc. In physical terms, it is a partially or fully ionised gas. It is classified into two types based on how it is generated. They are

- Cold plasma, or non-equilibrium or low-temperature plasma, and
- Hot plasma, or equilibrium or thermal plasma

Thermal plasma is formed at temperature around 20,000 K. It consists of electrons, ions, and gas molecules, all in a state of thermodynamic equilibrium. They are typically formed during welding arcs. All gas species in hot plasma are highly reactive due to thermal equilibrium. However, in non-thermal plasmas, the gas species are not uniformly reactive. The selection of gas composition is a critical parameter in generation of plasma and its reactive properties.

Cold plasma

Cold plasma is a partially ionised gas that is maintained at low temperatures and characterised by the presence of reactive species such as ions, radicals, and photons. Also referred to as non-equilibrium plasma, cold plasma exhibits a significant temperature difference between its various

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components. In this state, electrons possess extremely high thermal energy, often exceeding 10,000 K, while the neutral gas atoms or molecules remain near ambient temperature. Despite their high energy, the electron density within the plasma is significantly lower than that of the neutral species. In laboratory settings, cold plasma is typically generated by supplying electrical energy to inert gases. This process operates effectively under ambient conditions at room temperature and atmospheric pressure, removing the need for complex and expensive equipment.

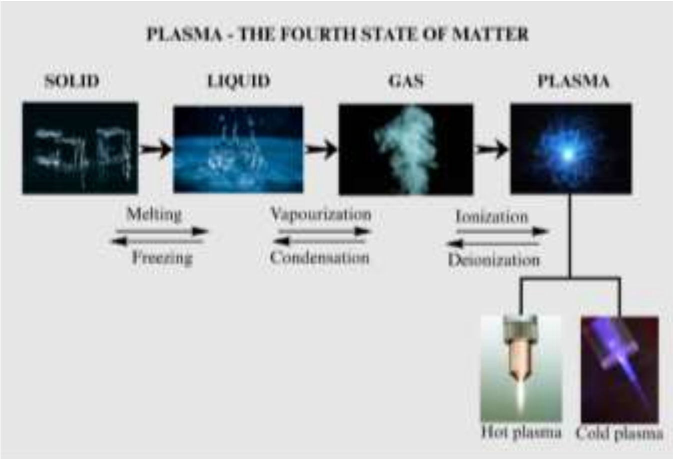

Figure 1. Plasma – The fourth state of matter

Generation of Plasma

Cold plasma is formed when electrical energy is applied to a gas, such as argon, helium, or even air, at either atmospheric pressure or lower. This energy partially ionises the gas molecules, producing a complex mixture of particles such as electrons, ions, radicals, neutral atoms, and excited species. The term "cold" refers to the fact that, although electrons in the plasma reach very high energy levels, the heavier species, such as ions and neutral atoms, remain at much lower temperatures, resulting in a low overall gas temperature close to ambient conditions. The cold plasma can be generated using various methods, including dielectric barrier discharge, corona discharge, microwave discharge, radio frequency discharge, and gliding arc discharge.

a) Dielectric barrier discharge

Dielectric barrier discharge (DBD) is a type of electrical discharge that occurs between two electrodes with an insulating material placed between them. It usually operates at frequencies between 0.5 and 500 kHz. It is also known as a silent discharge because it operates without noise. When high voltage is applied, plasma is generated at atmospheric pressure. One of the main advantages of DBD is that it can easily operate under normal atmospheric conditions, making it useful for applications like surface treatment and sterilisation.

b) Corona discharge

Corona discharge is a type of electrical discharge that happens when a fluid, like air, around a charged conductor becomes ionised. This occurs when the electric field near the conductor is strong enough to ionise the surrounding air and form a small conductive region but not strong enough to trigger a complete electrical breakdown or a spark to nearby objects. It usually appears as a bluish glow in the air near the conductor. Corona discharge is generated by applying high voltage to sharp or pointed electrodes, which intensify the electric field and facilitate the ionisation of the surrounding air.

c) Microwave discharge

Microwave discharge is a method of plasma generation in which microwave energy is used to ionise a gas and produce plasma. The microwaves excite the gas molecules, generating collisions that release electrons and initiate ionisation. This method efficiently generates high-density plasma with a high concentration of energetic electrons. It typically operates at microwave frequencies, commonly around 2.45 GHz, and can function under both low-pressure and atmospheric-pressure conditions.

d) Radio frequency discharge

Radio frequency (RF) discharge generates plasma by using alternating current at radio frequencies,

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typically around 13.56 MHz, to energise and ionise a gas. It usually operates under low-pressure conditions. It produces a stable, uniform, non-thermal plasma with high-energy electrons while maintaining low overall gas temperatures. Energy is coupled to the gas either capacitively or inductively, sustaining the plasma discharge efficiently.

e) Gliding arc discharge

Gliding arc discharge uses a high-voltage arc that forms between two diverging electrodes and moves along with the flow of gas. As the arc moves through the expanding gap, it stretches and cools, creating a non-equilibrium plasma that contains both thermal and non-thermal regions. This discharge produces a rich mix of reactive species, such as radicals and excited molecules. It operates efficiently at atmospheric pressure and is known for its high chemical reactivity.

Mechanism of Action

Cold plasma is produced by applying energy to gases like air, argon, or helium, leading to ionisation. This process generates a complex mixture of reactive species, including reactive oxygen species (e.g., O_3, •OH, O_2^-), reactive nitrogen species (e.g., NO, NO_2, $ONOO^-$), UV photons, electrons, ions, and metastable atoms and molecules. Reactive species target microbial cell walls and membranes, leading to lipid peroxidation, protein degradation, and increased membrane permeability. Once inside the cell, they induce DNA damage (such as strand breaks and base alterations), denature functional proteins, and deactivate essential enzymes. An excess of ROS and RNS overwhelms the microbial antioxidant defence systems, disrupting the redox balance and impairing essential metabolic functions. Combined membrane disruption, genetic damage, and enzyme inactivation lead to microbial lysis or apoptosis-like death.

Figure 2. Mechanism of Action of Cold Plasma

Applications

Cold plasma has been explored for a wide range of applications in food processing. Among these, surface decontamination of food products and packaging materials stands out as one of the most advanced and well-researched areas. It is commonly used across a variety of food products, including fruits, vegetables, meat, poultry, and seafood. The applications of cold plasma treatment on different food commodities are represented in Table 1. Cold plasma also preserves the natural colour, texture, and moisture content of foods while having little effect on nutritional components such as vitamins and antioxidants. Won *et al.* (2017) found that microwave plasma treatment of mandarins improved the phenolic content and antioxidant activity of their peel. The treatment can also lower the activity of spoilage-causing enzymes such as polyphenol oxidase (PPO) and peroxidase (POD), hence preventing browning. While flavour and aroma remain generally unchanged, extended exposure may cause minor changes. Overall, cold plasma extends shelf life while maintaining food quality.

In addition to decontamination, cold plasma also induces modifications in certain food packaging materials. Several researchers have reported that the use of cold plasma for package cleaning and container filling is beneficial. The chemicals and

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liquids required to sterilise bottles and containers generate a large amount of effluent, raising the expense of effluent treatment. Cold plasma can be utilised in such circumstances to reduce the use of chemicals while also having minimal effect on the packing material's properties. Cold plasma treatment can decrease the permeability of polymer materials to gases such as carbon dioxide (CO_2) and oxygen (O_2), enhancing their barrier properties. Ziuzina *et al.* (2014) reported that cold plasma treatment of packaged strawberries significantly reduced microbial populations, including pathogens such as *Salmonella* and E. *coli*, with treatment durations ranging from 60 to 300 seconds. Microbial reductions exceeding 3 log cycles were achieved without compromising the fruit's colour or firmness.

Table 1. Applications of cold plasma treatment on different food commodities

Food material	Plasma Treatment	Findings	Reference
Apple	The plasma was exposed to a mixture of argon and 0.1% oxygen for a duration of 480 seconds.	The population of *Citrobacter freundii* was reduced by 5 log cycles.	Surowsky *et al.* (2014)
Tomato	Dielectric barrier discharge	The *Listeria innocua* population was reduced to 3.50 log_{10} CFU per sample.	Ziuzina *et al.* (2016)
Cut apple and potato	A microwave-driven plasma torch operating at a frequency of 2.45 GHz, with an input power of approximately 1.2 kW and a gas flow rate of 20 L/min, was employed.	Decreased activity of PPO and POD enzymes, helping to prevent potato browning.	Bußler *et al.* (2016)
Pomegranate juice	A cold plasma jet was produced using argon, with a treatment duration of 3–5 minutes and a gas flow rate between 0.75 and 1.25 dm³/min.	Anthocyanin yield increased by up to 35%, likely due to enhanced extractability and the disruption of cell membrane integrity.	Kovačević *et al.* (2016)
Milk	Argon gas plasma was applied at frequencies of 2, 3, and 4 kHz for 2 minutes, and at 4 kHz for durations ranging from 30 to 120 seconds.	Compared to pasteurization, plasma treatment significantly lowered the bacterial population and improved microbiological quality during storage.	Ponraj *et al.* (2017)
Lamb meat	Dielectric Barrier Discharge f = 50 Hz, V = 80 kV, ET = 10min	2 log cycle reduction was observed in *Brochothrix thermosphacta* population.	Patange *et al.* (2017)
Chicken meat	He-O_2 plasma for 4 min	*Listeria innocua* levels dropped by more than 3.5 log units.	Noriega *et al.* (2011)

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Egg	**Eggs spiked with 10% *Salmonella enterica* were treated using DBD plasma at 25–30 kV (peak-to-peak) and 10–12 kHz frequency.**	**At 80% relative humidity, *Salmonella* levels dropped below the detection limit (10^7 CFU) after 10 minutes of treatment.**	**Georgescu *et al.* (2017)**

Future Prospects and Conclusion

Cold plasma is a developing non-thermal technique with strong potential to enhance food safety and extend shelf life without compromising quality. It effectively inactivates a wide range of microbes and alters the surface properties of food packaging materials, thereby increasing barrier function, printability, and antimicrobial activity. Despite its promise, industrial adoption is hampered by a lack of understanding about its impact on food quality, safety, and regulatory approval. Future research should focus on optimising treatment parameters, evaluating genotoxic and cytotoxic effects, and establishing GRAS status through comprehensive studies. To enhance commercial viability, innovation should focus on developing scalable and cost-effective systems that deliver consistent plasma exposure and precise process control, such as in-package plasma and plasma-activated water (PAW) technologies. Additionally, expanding research on plasma's interactions with various food matrices, nutrients, and possible byproducts is necessary for risk assessment and regulatory approval. Cold plasma has the potential to be a transformative solution for clean-label, high-quality, and safe food manufacturing as interdisciplinary collaboration among food scientists, engineers, and regulatory authorities expands. With more validation, cold plasma could become a crucial element in sustainable, safe food processing and packaging systems.

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Biogenic Polymer Coating for Better Seed Health Management

Mamta[1], Kinjal Mondal[1]
[1]Department of Molecular Biology and Biotechnology, Maharana Pratap University of Agriculture and Technology, Udaipur-313001 (Raj.), India

Seeds are fundamental to agriculture, ensuring crop propagation, genetic improvement and sustainability. Seed coating is a vital technology that enhances seed quality, protects against biotic and abiotic stresses, improves germination and crop yield. Traditional chemical coatings, while effective, pose environmental and health risks, prompting the exploration of bio-genic polymer coatings as eco-friendly alternatives. Among these, chitosan—a biodegradable, biocompatible polymer derived from seafood waste—has emerged as a promising seed coating agent. Chitosan coatings not only protect seeds from pathogens by inducing plant defense mechanisms but also promote beneficial microbial growth, enhance nutrient uptake and improve seedling vigor and stress tolerance. Various seed coating types, including film coating, pelleting and encrusting, facilitate uniform seed size and better mechanical sowing efficiency. Advances in biogenic polymer composites, especially chitosan-based formulations, offer sustainable solutions to reduce reliance on synthetic chemicals and fertilizers. Despite challenges in formulation and cost, chitosan-mediated seed coatings hold significant potential for sustainable agriculture, integrated pest management and global food security. Continued research and technological development are expected to optimize these coatings, making them indispensable tools for modern seed health management and precision farming.

Introduction

Seeds are the cornerstone of agriculture because they ensure the propagation, genetic improvement, economic viability, sustainability and diversity of crops, all of which are essential for feeding the growing global population and maintaining resilient agricultural systems. Seeds carry the heritable traits of plants, allowing for the selection and propagation of desirable characteristics (such as disease resistance, drought tolerance and higher productivity etc). In general, the quality seed is measured in terms of genetic and physical purity, germination, vigour, uniformity in sizes and freedom from seed-borne diseases (Vijay *et al.*, 2025). Seed health management is therefore considered as one of the key mandates to enable the spread of agricultural advancements. It is already known that coatings contribute to metabolic repairing in the seed during initial imbibition, building-up of the germination-enhancing metabolites, osmotic adjustment and the reduction in the lag-time of imbibition (Rocha *et al.*, 2019). However, despite of getting quick responses by the chemical treatment, it may lead to create chemical load in the environment as well as human being when used beyond recommendation. In this regard, exploring bio-genic polymer compounds as seed coating agents is thought to be a potential alternative, promising better seed health management along with environmental sustainability (Qazi *et al.*, 2025). Bio-genic polymer coatings represent a promising advancement in seed health management, offering enhanced protection, improved germination and sustainable agricultural benefits. These coatings use biodegradable, natural or bio-based polymers combined with beneficial microbes or agrochemicals to create a protective film around seeds, optimizing seed performance and crop yield. Biopolymers, such as hydroxyethyl cellulose, chitosan (CS), gelatine–gum form a thin, uniform film on the seed surface that can carry active ingredients like fungicides, insecticides, bioagents or microbial inoculants (Soltanzadeh *et al.*, 2022). Unlike conventional synthetic coatings, bio-genic polymers are environment friendly, non-toxic and degrade naturally in the soil without harming soil health. Herein, we've discussed how chitosan, a true

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representative of bio-genic polymer substances can be effective in seed coating for better crop output in modern agriculture.

1. Importance of seed coating before sowing

Seed coating modifies the seed's shape, size, weight and surface to make them more uniform and easier to handle mechanically. This uniformity reduces skips and doubles during mechanical sowing, ensuring better seed spacing and more accurate planting depth, which enhances germination conditions and plant development (Nardon *et al*.,2022). Coated seeds flow better through sowing equipment, reducing clumping and dust generation. Coating seeds can improve the germination rate by protecting seeds from biotic and abiotic stresses. The coating can include beneficial additives such as fungicides, insecticides, nutrients or bio-stimulants that promote seed viability and early seedling vigour. This leads to a more uniform, vigorous crop stand that optimizes competition for resources and ultimately increases yield (Stomph *et al*., 2020). Seed coating allows precise application of protective compounds directly to the seed, reducing the risk of seed rot, seedling blights and pest damage during early growth stages. This targeted protection reduces the need for broad pesticide application in the field, lowering environmental impact and exposure risks for workers. Coating also supports sustainable farming practices by improving seed use efficiency and reducing chemical runoff. Seed coating can be used to deliver beneficial microbes (plant growth-promoting bacteria and fungi), micronutrients and growth regulators precisely at the seed-soil interface. This enhances nutrient uptake, stress resistance and plant growth, improving yield and crop quality. Such coatings can be especially valuable in low-input agriculture to reduce fertilizer use and improve food nutritional value (Karthik *et al*., 2021).

2. Types of Seed Coating

Seed coating technologies include a broad spectrum of seed modification by a thin-layer film coating and pelleting process to the purpose of the improvement of seed plant ability through accurate machine planting, improve germination, emergence, final plant stand, however, have gained significant advancements in alleviating various potential problems (Afzal *et al*., 2020). Different types of seed coating may be used in agriculture for better seedling growth, as described below (Figure 1):

A. **Film Coating:** Thin polymer layer that adheres active compounds without changing seed shape; reduces dust and improves flow.

B. **Pelleting:** Surrounds seed with a shell, increasing size and weight for uniform shape, improving handling.

C. **Encrusting:** Similar to pelleting but retains more of the original seed shape, also improving size, weight, and uniformity.

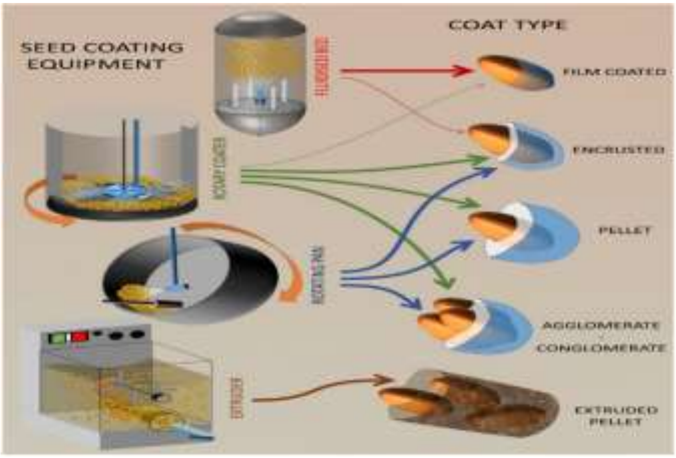

Figure 3: Types of seed coating for better seed health management

3. Biogenic polymers as potential seed coating agents: scope & relevance

The polymer seed-coatings have been practiced without microbial strains to regulate seed germination and the emergence of fall-seeded grain crops. To improve the utility and cost efficiency of different seed-coating techniques, it is necessary to understand the metabolic events that take place in seed during coatings. This seed-coating technology is expected to replace or substantial reduction of the synthetic chemical fertilizers and artificial growth regulators, which have numerous side-effects to sustainable agriculture. The integration of biogenic nanoparticles with polymers, creating synergistic effects in composite materials by combining inherent nanoparticle properties with the processability and flexibility of polymers (Qazi *et al*., 2025). Various synthesis methods for polymer composites reinforced with biogenic nanoparticles, including solution mixing, melt mixing, *in situ* polymerization and microwave irradiation offer effective ways to achieve desired material properties and uniform distribution of nanoparticles within the polymer matrix. The potential of biogenic nanoparticles in enhancing the mechanical, electrical, optical and thermal properties of polymeric nanocomposites is analyzed comprehensively. Biogenic nanoparticles exhibit the capability to enhance mechanical properties through strong molecular interactions with polymer matrices. The substantial improvement in electrical conductivity results from the increased carrier density and enhanced electron mobility associated with the nanoparticles (Usman *et al*., 2020). The reduction in energy gap (EG) values is linked to the generation of defects caused by the presence of nanoparticles and the formation of charge transfer complexes within the composite material. Additionally, their use in polymer composites aligns with sustainable and eco-friendly approaches, derived from renewable natural sources, reducing reliance on synthetic materials.

Of various biogenic polymers, chitosan (a deacetylated form of chitin) plays a significant role in various fields due to their sustainable, biodegradable and biocompatible properties (Ediyilyam *et al*., 2022). Popularly, they are used to make sustainable and biodegradable lubricating agents, bio-based epoxy resins, and peptide-polymer conjugates that interact beneficially with living cells. This versatility allows for fine-tuning material properties for optimized performance in various applications. The development of biogenic polymers is crucial for reducing reliance on petrochemical plastics, thus addressing environmental concerns related to plastic pollution.

4. Chitosan-mediated seed coating for better seedling growth

Chitosan is a naturally originated biopolymer obtained commercially from seafood shells, making use of waste products from the seafood industry (Santos *et al*., 2020). Chitosan acts as a bio-fungicide, bio-bactericide and bio-virucide, inducing plant defence mechanisms against pathogens. It enhances the immune response in plants by activating defence signalling pathways and eliciting phytoalexins and pathogenesis-related proteins (Mukarram *et al.,* 2023). Chitosan serves as a biofertilizer that promotes beneficial rhizobacteria growth and improves nutrient uptake in plants. Its coating ability helps reduce fertilizer losses, minimizing environmental pollution from excessive fertilizer use. Chitosan also acts as a bio-stimulant enhancing seed germination, seedling growth, and overall plant development, leading to increased crop yield (Chandrasekaran & Paramasivan, 2024). Chitosan is a large cationic polysaccharide mainly obtained from waste materials from seafood processing. It is reported that chitosan-based nanoparticles have significantly influenced seed physiology by modulating the enzymatic activities of germinating corn seeds under favourable conditions (Choudhary *et al*., 2017). Activated α-amylase and protease remarkably interfere the utilization of reserved food during germination at the dawn of life (Figure 2). Seed soaked with chitosan increased the energy of germination, germination percentage, lipase activity, and gibberellic acid (GA_3) and indole acetic acid (IAA) levels in peanut (Babasaheb, 2020).

Hence, chitosan is thought to function as a potential candidate in favour of seed health management.

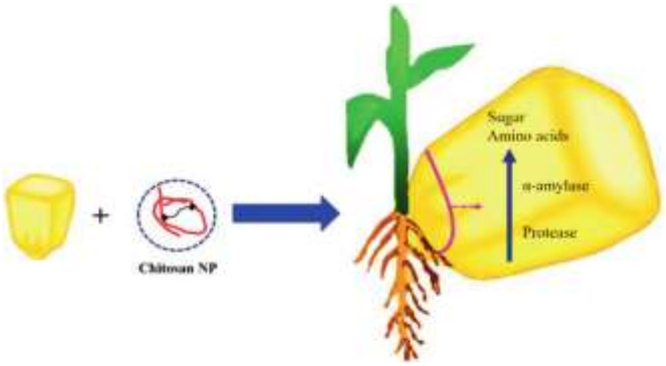

Figure 2: Chitosan NPs promote enzyme activity of germinating seeds and boost seedling emergence

5. Future prospects and conclusion

The chitosan market is growing rapidly due to its eco-friendly applications in agriculture, especially seed treatment. Chitosan enhances germination, seedling vigor, and crop yield while reducing chemical use. Advances in extraction and nanotechnology improve its effectiveness and cost-efficiency. Its biodegradability, antimicrobial properties and ability to boost plant immunity make it ideal for sustainable farming and integrated pest management. Future seed coatings may combine chitosan with other bioactive agents to improve soil health and precision farming. Despite challenges like formulation complexity and cost, increasing regulatory support and farmer demand are driving adoption. Chitosan-based coatings represent a promising, sustainable solution for improving seed health and global food security. Continued research and development will further optimize these coatings making them indispensable tools for next-generation seed technologies.

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From wellspring to wasteland? The cultural and environmental significance of wells in rural india and their current crisis

Devyansh Pandey

Why Saving the Village Well Is More Than Just a Drop in the Bucket-

Saving the cultural history of India also includes the Village Well and its Significance, Visit an Old Indian village you will surely witness the silence and peace which reflects decades and decades of life, the village wells, Covered with dust weakened and broken at the very edges and filled with trash and garbage today, But once it was seen as the very Important to community

It wasn't just about water. It was about the connection we share. About stories, seasons, and sustainability. And yet, in today's rapidly changing rural landscape, wells are being forgotten and restrained by bore wells, piped water schemes, and a culture that is drifting away from its roots.

What are we REALLY LOSING?

In rural India, the well was where life happened.

Every morning and evening, women gathered here with pots on their heads not just for water, but for community. They exchanged songs, shared village gossip, and taught the next generation how to balance a matka with grace.

Wells were deeply woven into rituals blessing ceremonies, marriages, harvest festivals. Often considered sacred, many had tulsi plants, painted stones, or even idols guarding them.

They were social hubs, spiritual centres, and environmental solutions all rolled into one humble structure.

A Natural, Sustainable Water System-

Unlike bore wells that drill deep into aquifers and deplete water reserves, traditional open wells worked with nature. They tapped into shallow water tables and allowed for natural recharge during the monsoon.

The design was simple, built from local stone and soil, with an intimate understanding of the land's behavior. No motors. No concrete tanks. Just community wisdom and respect for natural limits.

They taught us something we're rapidly forgetting:

Water is not unlimited.

Where Did we Go wrong?

With the cost of Modernisation came bringing with it bore wells, hand pumps, tankers, and now, piped water schemes. These are fast, easy, and often government sponsored. In contrast, wells seem slow and outdated.

But that convenience came with various consequences:

- Groundwater is over-extracted.
- Wells are drying up or getting contaminated.
- Traditional practices are fading.
- And perhaps worst of all people no longer know where their water comes from.

The well, once used to be a symbol of community and care, and is now either locked, broken, or worsen used as a garbage pit.

Is it Possible to Bring Them Back?

Yes, we can and some people already are.

Across India, small initiatives are cleaning, reviving, and celebrating old wells. They're being de-silted, decorated, and turned into community rainwater harvesting points. In some villages, reviving wells has brought back groundwater levels and even helped during droughts.

But the real challenge? **Mindset.**

Many see wells as outdated relics. Without community ownership, these efforts risk being temporary fixes.

Why It Matters?

Restoring wells is not just an act of nostalgia it's an act of climate resilience. It's a way to reconnect people with their water sources. It's about respecting traditional ecological knowledge. It's about giving rural youth a appropriate reason to care about sustainability through something that's local and tangible.

We don't need to choose between the past and the future.

We just need to virtue the past while building a smarter future.

Final Thought: The Well Is a Mirror-

The state of our village wells reflects the state of our relationship with nature. If the well is dry, polluted, or forgotten so is our connection to the Earth.

So next time when you walk past an old well, stop. Look in. Not just for water but for the reflections of a wiser time.

Maybe it's time we drew from that well again.

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Eco-friendly Approaches for Plant Disease Management: Strategies and Perspectives

Krishna Kumar, Sahadeva Singh and Uzma Manzoor

School of Agriculture, Galgotias University, Greater Noida-201310, UP, India

Introduction

Plant diseases lower crop yields and quality, which is a serious challenge to global food security. Chemical fungicides and insecticides have historically been the main instruments used to control these illnesses. But excessive use of these has resulted in health risks, environmental contamination, and the creation of resistant types of pathogens. Eco-friendly strategies that provide long-term, secure, and efficient disease management solutions have become more popular as a result. Biological control, botanicals, molecular tools, cultural practices, and integrated disease management strategies are some of these techniques. These methods seek to increase crop output, maintain ecological balance, and reduce reliance on chemicals. Eco-friendly plant disease management provides a useful route to sustainable agriculture by fusing ancient wisdom with contemporary science, protecting the environment and human health for coming generations.

1. Cultural Practices

The oldest and most widely used strategy for controlling plant diseases is cultural practice. By altering agronomic procedures including crop rotation, soil management, and planting schedules, these methods seek to make the environment unfavorable for infections. Cultural practices, such as the use of pathogen-free seeds, good field cleanliness, and strategic crop rotation, lower the inoculum load and postpone the development of disease, according to Singh and Chawla (2012). A non-chemical method of disease control is provided by techniques like soil solarization and modifying the sowing time that inhibit soil-borne diseases and interfere with pest life cycles.

2. Biological Control

Biological management suppresses plant diseases by using living things like fungi, bacteria, and helpful viruses. According to Sharma *et al.* (2017), biocontrol agents such as Bacillus subtilis, Pseudomonas fluorescens, and Trichoderma spp. work against pathogens via generated systemic resistance, competition, and antibiosis. These substances support sustainable agriculture by improving soil health and plant growth in addition to controlling infections (Kumawat *et al*., 2025).

Biocontrol agents do have drawbacks, though. Under field situations, their performance may vary depending on the surroundings. Furthermore, technological know-how is needed for formulation, manufacture, and application. Notwithstanding these drawbacks, biological control is still a potentially useful instrument in integrated disease management systems since it lessens the need for chemical pesticides.

3. Ecological Approaches in Organic Farming Systems

The goal of organic farming methods is to preserve ecological balance by promoting soil health and biodiversity. Strategies include utilizing disease-resistant cultivars, increasing soil microbial diversity, and applying organic amendments that reduce infections were described by Koike *et al.* (2007). Although resistance may erode over time as a result of pathogen evolution, choosing cultivars that are resistant to disease is crucial. By preventing pathogen accumulation in the soil, site selection and crop diversity further lower disease risks.

Another important tactic is exclusion, which involves using hygienic practices and verified disease-free seeds to stop pathogens from entering. Exposure to chronic soilborne infections can be reduced by crop rotation and cautious field selection based on established disease histories.

4. Botanical Pesticides and Physical Methods

As an environmentally beneficial substitute for synthetic insecticides, botanical pesticides are made from plant extracts. They can be combined with other disease control techniques, are biodegradable, and are less harmful to non-target organisms. Physical techniques to combat seed and soil-borne diseases include hot water seed treatment and soil solarization (Singh *et al*., 2012). Despite being safe, these techniques might need to be used carefully to guarantee their effectiveness.

5. Molecular and Biotechnological Innovations

Novel approaches to disease resistance breeding have been made possible by recent developments in biotechnology and molecular biology. Crops with increased resistance to infections are being developed using genetic engineering, RNA interference (RNAi) technologies, and the use of disease resistance genes. Although these methods offer long-term fixes, biosafety issues have caused differences in consumer and regulatory agency adoption.

6. Integrated Disease Management: A Holistic Approach

It is uncommon to handle plant diseases effectively using a single technique. In order to accomplish sustainable disease management, Integrated Disease Management (IDM) integrates cultural, biological, physical, chemical, and biotechnological approaches. These techniques work in concert to maximize effectiveness and reduce environmental impact. IDM is further improved by forecasting models and disease warning systems, which allow for prompt interventions.

Conclusion

Sustainable agriculture depends heavily on environmentally friendly disease management techniques, especially in light of growing global food demands and environmental concerns. While each approach has pros and cons, the most effective way to create resilient agricultural systems is to combine them into an IDM framework. Future studies should concentrate on improving the use of molecular tools, investigating new botanicals, and improving biocontrol technologies-all the while encouraging farmer education and policy support.

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Panchagavya: An Eco-friendly Approach for Sustainable Agriculture and Plant Disease Management

Krishna Kumar, Uzma Manzoor and Sahadeva Singh
School of Agriculture, Galgotias University, Greater Noida-201310, UP, India

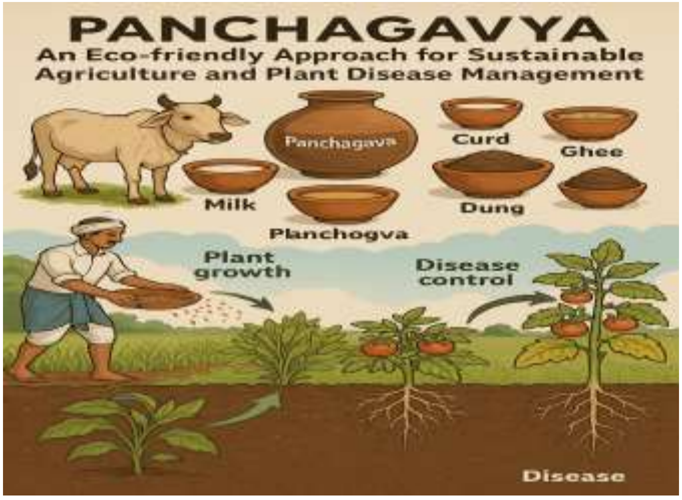
Introduction

Modern agriculture's abuse of chemical pesticides and fertilizers has harmed soil quality, polluted the environment, and put human health at danger. This made looking for sustainable substitutes necessary. Panchagavya is a traditional formulation that promotes organic farming and plant health management. It is made up of five cow-derived products: cow dung, urine, milk, curd, and ghee. Panchagavya is renowned for its biofertilizer and biopesticide qualities and has been mentioned historically in Vrikshayurveda and other ancient writings (Natarajan, 2002). Panchagavya is an essential part of integrated pest management because, in addition to increasing plant growth and productivity, it creates systemic resistance against pests and diseases. Due to its many advantages, organic farming has garnered increased interest from scholars and practitioners around the world.

A powerful bio-stimulant in sustainable agriculture, panchagavya is a traditional Indian organic preparation made from cow-based products such as dung, urine, milk, curd, and ghee.

Traditionally used in Ayurvedic medicine and religious ceremonies, it is now essential for improving soil fertility, encouraging plant growth, and environmentally friendly plant disease management. The scientific underpinnings of Panchagavya's use in agriculture are highlighted in this paper, along with the advantages it offers in terms of increasing crop yield, preventing plant diseases, and promoting sustainable farming methods.

Preparation and Components of Panchagavya



In order to prepare panchagavya, three kilograms of fresh cow dung, three liters of cow urine, two liters of cow milk, two kilograms of curd, and one kilogram of ghee must be fermented. In a plastic container, the ingredients are combined, stirred twice a day, and left to ferment for two to three weeks. To increase microbial activity, other ingredients such as gram flour, jaggery, bananas, and soft coconut water are occasionally included (Chadha et al., 2012).

Beneficial microorganisms including actinomycetes, lactic acid bacteria, yeasts, photosynthetic bacteria, and fungus are present in the preparation. In the soil, these microbes aid in nitrogen fixation, phosphorus solubilization, and nutrient cycling. The resulting Panchagavya solution turns into a storehouse of vitamins, amino acids, enzymes, and plant growth hormones (auxins, gibberellins, and cytokinins).

Agronomic Benefits of Panchagavya

Application of Panchagavya, whether by foliar spray, soil soaking, or seed treatment, has been shown in field trials to greatly increase crop growth

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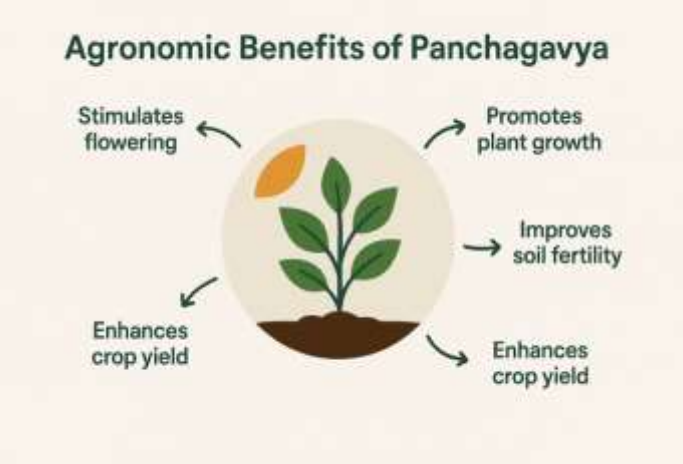
metrics like plant height, branching, leaf area, and root proliferation. Strong vegetative growth results from the acceleration of cell division and elongation caused by growth-promoting chemicals (Beaulah, 2001).



Yield Enhancement

In a variety of crops, including wheat, tomato, okra, and coriander, panchagavya improves flowering, fruit setting, and yield characteristics. Research shows increased fruit output, weight, and size as a result of enhanced photosynthetic efficiency and better nutrient uptake (Pagar et al., 2015). Panchagavya also improves the market quality of harvested produce and prolongs its shelf life.

Soil Fertility Improvement

Applying Panchagavya promotes the formation of beneficial soil microorganisms and enriches the soil with macro- and micronutrients. This enhances aeration, water retention, and soil structure, all of which support long-term soil fertility. Its organic composition improves nitrogen cycling by providing soil bacteria with a carbon source.

Panchagavya in Plant Disease Management

Biocontrol Activity

Against a variety of plant diseases, panchagavya demonstrates antifungal and antibacterial qualities. Its efficacy against soil-borne pathogens such as *Rhizoctonia solani, Sclerotium rolfsii*, and *Fusarium solani* has been validated by in vitro experiments. Panchagavya's antibacterial substances inhibit the growth of pathogens and stop the spread of sickness (Dogra, 2006).

Integrated Disease Management

The management of wilt, damping-off, and other fungal diseases in vegetable crops has shown encouraging results when Panchagavya is combined with additional organic inputs like Kunapajala and vermiwash. Regular application improves plant immunity and lessens the need for chemical pesticides.

Environmental and Economic Significance

By lessening the environmental impact of chemical inputs, Panchagavya adoption promotes environmentally responsible agriculture. It provides an affordable, farmer-friendly option that complies with organic farming regulations. Additionally, it encourages the use of domestic cow-based goods, giving traditional farming methods and cattle husbandry more economic significance.

Conclusion

A versatile tool in sustainable agriculture, panchagavya promotes plant development, increases yield, improves soil health, and offers environmentally friendly disease control. It is a good substitute for chemical pesticides and fertilizers because of its historical origins and current scientific support. Panchagavya is a comprehensive farming

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input that promotes ecological balance and increases agricultural ecosystems' resilience.

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Exploring Nutritional Security and Sustainable Development in Aspirational Districts of India

Raksha[1] Pooja, V.[2] and Mallika Meti[3]

[1]Assistant Professor, Faculty of Science, Siddharth University, Siddharth Nagar, Kapilvastu, UP

[2]Ph.D. Research Scholar, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India

[3]Assistant Professor, Extension Education, University of Agricultural Sciences, Raichur, Karnataka

Nutritional security is always a matter of concern and discussion from the civilization. Any nations; development depends on the various factors out of which the nutrition and health are one of the important factors as the heathy citizens contribute in any nation's development. Nutritional security covers various aspects like availability, accessibility, utilization and distribution. This further varies with at national level, state, district and family level. There are various parameters to assess the nutritional status of a family or the country itself. This concept further becomes an important point for discussion in case of aspirational districts. Aspirational districts are those districts which are lagging behind in terms of development. This development could be in the areas of health, nutrition, education, infrastructural development, poverty and so on. This papers examines the basics of nutritional security with a twist of figures and future strategies associated with it.

Introduction

Nutritional security is a crucial component of sustainable development, especially in the context of Aspirational Districts in India. The country has long struggled with issues related to malnutrition, stunting, undernutrition, and micronutrient deficiencies, particularly in rural and backward areas. These challenges are often exacerbated by poor healthcare infrastructure, lack of awareness, and limited access to nutritious food.

Nutritional Security and its key components

Nutritional security refers to the reliable access to sufficient, nutritious, and safe food that meets the dietary needs and food preferences for an active and healthy life. It's about ensuring that individuals, especially vulnerable populations such as children, pregnant women, and the elderly, receive the right kind of food in the right quantity and quality. Achieving nutritional security goes beyond just food availability it involves factors like food access, utilization, and stability.

The USDA defines nutrition security as "consistent and equitable access to healthy, safe, and affordable foods that promote optimal health and well-being." Food insecurity is defined as a household-level economic and social condition of limited or uncertain access to adequate food while nutrition security refers to an individual or household condition of having equitable and stable availability, access, affordability, and utilization of foods and beverages that promote well-being, prevent disease, and if needed, treat disease.

The concept of nutritional security covers basically four concept: availability, accessibility, utilization and stability. Further these four parts are governed by various points.

1. **Food Availability:** It depends on two factors production and supply chain.

- **Production**: There must be a consistent supply of a variety of food products that are nutrient-dense. This could involve local food production through agriculture or access to diverse food markets.

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- Supply Chain: The food should be available not only at the national level but also accessible at the household and local community level. Local food systems and markets need to function efficiently.

2. Food Access: It covers basically accessibility at economic level and physical mode. There is also food accessibility at individual level and family level.

- Economic Access: People must have the financial means to purchase food, which is often a barrier for low-income households. Economic stability, employment, and income-generating opportunities are crucial here.

- Physical Access: Proximity to markets, transportation, and infrastructure also play a role. People living in remote or rural areas often struggle with limited access to nutritious foods.

3. Food Utilization: food utilization is affected by various factors; say; quality, health status, sanitation and environment and dietary diversity. It could be further understood as-

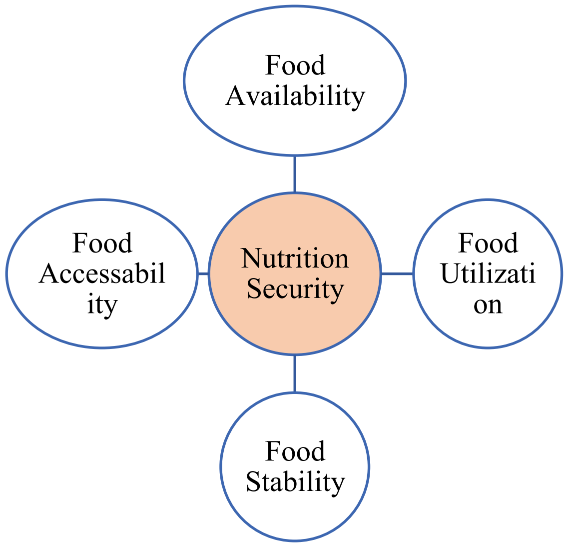
- Nutrient Quality: It's not just about the quantity of food, but also the quality. Food needs to provide the essential nutrients, including vitamins, minerals, and proteins, that the body needs for growth, development, and overall health.

- Health and Sanitation: Proper sanitation, healthcare, and hygiene are important for ensuring that the food consumed can be effectively utilized by the body. Poor health, waterborne diseases, or lack of clean drinking water can interfere with nutrient absorption.

- Dietary Diversity: A diverse diet is key to ensuring that all necessary nutrients are provided. This includes fruits, vegetables, whole grains, proteins (e.g., pulses, legumes, meat, fish), dairy, and healthy fats.

4. Food Stability

- Sustainability: Food must be stable over time. This means ensuring that the availability of food remains consistent year-round, without seasonal shortages, price hikes, or interruptions due to climate change, economic instability, or political disruptions.



- Resilience to Shocks: The food system must be resilient to shocks, such as natural disasters, economic crises, or conflicts, which can disrupt food supply chains and impact access to food.

Aspirational Districts and Nutritional Security

Nutritional security means ensuring that people have reliable access to sufficient, nutritious, and culturally appropriate food at all times to maintain an active and healthy life. For many districts in India, especially those classified as "aspirational," the focus is on improving the nutritional outcomes for vulnerable populations like children, pregnant women, and the elderly. Besides various challenges to an aspirational district, nutritional security is one the major challenge. There are 112 districts in the country which falls under aspirational districts. These districts are spread from north India to eastern part to westerns and southern parts. Each part and state has its own unique strategies to develop and mainstream these aspirational districts into the development mainstream. In terms of nutritional security, on an average the problems occurring in these districts are;

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1. Malnutrition and Stunting: Many districts, especially in tribal and rural areas, struggle with high rates of stunting (low height-for-age) and underweight children. These conditions have long-term impacts on cognitive development and economic productivity.

2. Micronutrient Deficiency: A significant percentage of children and women in these districts suffer from micronutrient deficiencies, particularly iron, vitamin A, and iodine. This leads to anaemia, poor immunity, and impaired growth.

3. Food Insecurity: Lack of access to sufficient food, either due to poverty or poor agricultural practices, often leads to food insecurity, which is compounded by climatic events like droughts and floods.

4. Inadequate Diets: Many rural households rely on a staple diet that is not nutritionally diverse, often lacking in fruits, vegetables, proteins, and other vital nutrients.

Interventions to Improve Nutritional Security in aspirational districts.

To improve the nutritional security status in aspirational districts, various programmes and schemes are running by the government from time to time. These programmes and schemes can vary from state to state depending on the food culture, choices, preferences and the needs and demands. Below are some common programme mentioned to solve the issue of nutritional security in the mentioned districts.

The Aspirational Districts Programme has taken a holistic approach to address nutritional security. Here are some of the key interventions:

1. Public Distribution System (PDS) Reforms

- **Strengthening PDS**: In many aspirational districts, the PDS system is being revamped to ensure the delivery of fortified rice, wheat, and pulses. Fortification of staple foods like rice and wheat with essential vitamins and minerals is a key measure to combat micronutrient deficiencies.

- **Targeted Public Distribution**: There is a focus on ensuring that the most vulnerable populations—such as pregnant women, children, and the elderly—receive adequate rations.

2. Mission Poshan 2.0 (Integrated Nutrition Support Programme)

- This is a national mission that aims to address the nutritional needs of children, adolescents, pregnant women, and lactating mothers, with special emphasis on the most backward regions, including the aspirational districts.

- Key components include nutrition-specific interventions like the distribution of nutrition kits, the promotion of breastfeeding, and the introduction of Community-based Management of Acute Malnutrition (CMAM) programs.

3. Anganwadi and Midday Meal Schemes

- Anganwadi Centers serve as critical touchpoints for children under six years and pregnant/lactating women. The scheme provides supplementary nutrition, health education, and early childhood care, which is essential for improving nutrition and health outcomes.

- The Midday Meal Scheme focuses on providing hot, cooked meals to children in government schools, ensuring they receive at least one nutritious meal per day.

4. Improved Agricultural Practices

- Promotion of Nutrient-Dense Crops: Sustainable agricultural practices are being encouraged to increase the availability of diverse, nutrient-rich crops like pulses, vegetables, fruits, and legumes. These are also more resilient to climate change.

- Agroecology and Diversified Farming: Encouraging practices like crop rotation, organic farming, and mixed cropping systems helps build

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nutritional resilience by improving food diversity and ecosystem sustainability.

5. Health and Sanitation Infrastructure

- Improving healthcare access and sanitation is vital for nutrition. Many aspirational districts lack sufficient healthcare facilities and clean drinking water, leading to waterborne diseases and poor absorption of nutrients.

- The Swachh Bharat Abhiyan (Clean India Mission) complements efforts to improve sanitation and hygiene, which in turn prevents malnutrition caused by infections and diseases.

6. Nutrition Awareness Campaigns

- Awareness and education are essential to changing dietary habits. Local communities are being educated on the importance of a balanced diet, the impact of stunting, and how to utilize locally available foods for nutritional benefit.

- Community Nutrition Programs are being organized to provide information on the benefits of breastfeeding, the importance of micronutrients, and alternative sources of nutrition when access to expensive food items is limited.

7. Microfinance and Women's Empowerment

- Self-Help Groups (SHGs) are being promoted to increase women's participation in local governance, micro-enterprises, and agricultural production. Empowering women, particularly in rural districts, helps in improving the nutritional security of the entire household.

- Women in these groups are often trained in the production of fortified food products or sustainable agricultural practices that increase the diversity of their food baskets.

Conclusion

In India, many aspirational districts face challenges in achieving nutritional security. These regions often deal with poverty, poor healthcare, limited access to diverse food, and low levels of nutrition awareness. As part of India's Aspirational Districts Programme, efforts are being made to improve nutritional security by addressing these core issues:

- Improving access to fortified foods and essential micronutrients.
- Promoting local, sustainable agriculture to increase food diversity and reduce dependency on a limited range of crops.
- Strengthening public health and sanitation to ensure better food utilization.
- Introducing nutrition awareness programs to educate people about healthy diets.

In these regions, improving nutritional security is essential for addressing the underlying issues of poverty, poor health, and low productivity, while also contributing to achieving India's Sustainable Development Goals (SDGs), particularly SDG 2-Zero Hunger and SDG 3-Good Health and Well-being.

In summary, nutritional security is a multi-dimensional challenge that involves access to sufficient, diverse, and nutritious food, effective healthcare, and strong community engagement. Achieving it requires efforts from governments, local communities, and international organizations to address the various barriers, with a focus on sustainability, resilience, and equity.

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Impact of Carbon Markets on Farm Incomes

Rita Fredericks

CEO, Precision Grow (A Unit of Tech Visit IT Pvt Ltd)

Carbon markets offer a promising opportunity for farmers to enhance income while contributing to climate change mitigation. By adopting climate-smart practices such as conservation tillage, agroforestry, and organic farming, farmers can generate carbon credits and sell them in voluntary or compliance markets. These markets provide financial incentives, improve soil health, and support sustainable agriculture. However, challenges such as high transaction costs, technical barriers, and land tenure issues limit smallholder participation. With supportive policies, low-cost MRV systems, and capacity-building efforts, carbon markets can become a transformative tool for rural development and environmental sustainability in the agricultural sector.

Introduction

Climate change ranks among the biggest threats of our era, with deep implications for agriculture, food security, and rural livelihoods. Agriculture is a significant source of greenhouse gas (GHG) emissions through activities like conventional tillage, overdependence on synthetic fertilizers, rice cultivation, and animal husbandry. Yet, it has tremendous potential for climate change mitigation in the form of carbon sequestration and sustainable land management practices.

Here, carbon markets have come up as a novel and market-based approach for emission reduction and sustainable agriculture. Here, carbon credits can be traded, where each credit is equal to the avoidance or removal of one metric ton of CO_2e. Farmers earn credits by adopting climate-smart methods like conservation tillage, organic production, agroforestry, cover crops, and better livestock management. These credits are subsequently on-sold to organizations or businesses looking to neutralize their carbon footprint, generating new income for farmers. De Pinto *et.al.* 2010.

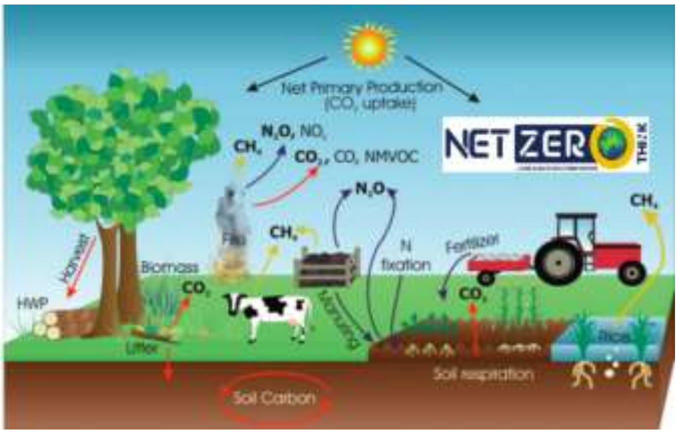
Carbon markets provide a two-pronged benefit—climate sustainability and increased incomes for farmers. They provide financial incentives for farmers to transition to sustainable practices and meet national and international climate objectives. For marginal and small farmers, carbon markets can be life-changing, and through them, diversify revenues, decrease input expenses, and enhance soil quality. But all this relies on a number of parameters such as access to technical information, inexpensive certification, and beneficial policy environments.

As the carbon economy expands, knowledge about its effects on farm incomes is important for constructing inclusive, sustainable, and climate-resilient agriculture systems.

3. Understanding Carbon Markets

3.1 What is a Carbon Market?

A carbon market is an organized trading system through which carbon credits—each denoting the avoidance or sequestration of one metric tonne of CO_2e—are bought and sold. The intrinsic goal of carbon markets is to assign a financial value to carbon emissions, thus motivating reduction efforts.



Source: https://www.linkedin.com

There are two main types of carbon markets:

Compliance Markets:

These are controlled by national or international legal regimes. Governments put a cap on the overall level of emissions and permit companies to sell or purchase allowances when necessary. Instances are the European Union Emissions Trading System (EU ETS) and California's Cap-and-Trade Program.

Voluntary Markets

These are beyond regulatory requirements. Here, businesses and individuals buy carbon credits voluntarily to cover their emissions as part of corporate sustainability targets or climate action. Voluntary carbon markets are overseen by standards like Verra (VCS) and Gold Standard in the certification and validation of voluntary market projects. Han *et.al.* 2023.

3.2 Agriculture's Role in Carbon Markets

The agriculture sector plays a big role and a dual one in the carbon market—as both an emission source and a sequestration sink for carbon. Through certain sustainable practices, farmers can be of help in carbon mitigation efforts and earn credits to be traded.

Major agricultural practices that help sequester carbon are:

- Improvement of soil carbon through conservation tillage and organic amendments
- Carbon capture by using agroforestry systems in biomass
- Strategies for decreasing methane in rice paddies and livestock management
- Organic farming and cover crops to decrease reliance on synthetic inputs

By entering the carbon markets, farmers contribute to mitigating climate change while also unlocking new revenue sources by selling verified carbon credits to purchasers worldwide.

4. Mechanisms for Farmer Participation

Involvement in carbon markets offers farmers a special opportunity to earn extra revenue while helping mitigate climate change. For farmers to participate effectively, they need to grasp the processes of how they can earn and sell carbon credits. These involve the adoption of climate-smart techniques, engagement with aggregators, and compliance with strong monitoring frameworks.

4.1 Producing Carbon Credits

Farmers earn carbon credits through the implementation of validated practices that reduce or sequester greenhouse gas emissions. These can be conservation tillage, agroforestry, enhanced manure management, or organic farming. For legitimacy, these practices are validated by third-party agencies that are accredited under recognized standards such as Verra (VCS), Gold Standard, Climate Action Reserve (CAR), and Clean Development Mechanism (CDM). The validated emission reductions are then translated into carbon credits, which can be sold in compliance or voluntary markets, generating a new source of income for farmers.

4.2 Aggregators and Cooperatives

As individual smallholder farmers might not contribute enough volume for direct market entry, aggregators or cooperatives are crucial. These groups aggregate the emission reductions from several farms to make the project financially feasible and market-appealing. They also provide training, data management, certification procedures, and market connections, lessening the load on individual farmers.

4.3 Monitoring, Reporting, and Verification (MRV)

A key component of carbon market credibility is MRV. It is a system where baseline emissions are

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determined, field checks are done periodically, and newer technologies like remote sensing, drones, and AI are employed to track reliably at low costs. A good MRV mechanism provides transparency, increases buyer trust, and delivers long-term gains to farmers involved.

5. Economic Benefits to Farmers

Carbon markets offer smallholders and farmers a groundbreaking chance to diversify and raise their income. By embracing carbon-saving activities and producing quantifiable carbon credits, farmers, in addition to supporting environmental sustainability, connect themselves to an expanding global economy based on climate resilience.

5.1 Another Source of Income

Participation in carbon markets is one of the immediate and concrete advantages of farmers, yielding additional income. By adopting accredited climate-smart activities, farmers receive carbon credits, which are then sold to clients in voluntary or compliance markets. The price of these credits usually varies from \$5 to \$30 per tonne of CO_2-equivalent, depending on the type of project (e.g., soil carbon, agroforestry), geographical location, certification standard (Verra, Gold Standard, etc.), and market demand at the time. This additional source of revenue can sustain farm investments, household incomes, and debt repayment.

5.2 Incentives for Sustainable Farming

Carbon finance promotes the adoption and implementation of sustainable agriculture practices like conservation tillage, organic fertilizer use, crop diversification, and agroforestry. These methods not only lower the rate of emissions but also enhance soil health, reduce reliance on chemical inputs, and enhance crop yields with time. The monetary incentives offered through carbon markets serve as a driver of long-term ecological care.

5.3 Rural Employment Opportunities

Carbon farming initiatives typically need to be carried out by trained staff for data monitoring, reporting, and field operations. This provides employment opportunities in rural locations—youth, women, and local communities being involved in training delivery, soil analysis, and MRV (Monitoring, Reporting, and Verification), and contributing to rural development and capacity building.

6. Challenges and Constraints

Although carbon markets have immense scope to increase farm revenues and encourage sustainable farming, a number of restraints restrict the entry and benefits to small and marginal farmers. It is essential to address these hindrances to make carbon markets more effective and inclusive.

6.1 High Transaction Costs

One of the significant impediments for smallholders is the exorbitant price of entry. Certification, monitoring, and verification (MRV) costs are high and in most cases prohibitive for individual farmers. Such costs can take a big chunk of the revenue from carbon credits, making net profitability low.

6.2 Technical Complexity

Carbon credit mechanisms entail sophisticated processes that need technical expertise in aspects like GHG emission accounting, MRV requirements, and legal agreements. Lacking the appropriate training and capacity-building assistance, the majority of farmers are unable to cope with the technicality of carbon finance.

6.3 Market Volatility

The value of carbon credits in voluntary markets can vary broadly, contingent on worldwide demand, policy shifts, and customer choices. This introduces uncertainty of income, which makes it risky for

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farmers who put time and money into carbon farming ventures.

6.4 Equity and Access Issues

Marginalized farmers, especially women, tribal communities, and landless laborers, often lack access to technology, credit, and information, preventing their inclusion in carbon projects. Without targeted outreach, these groups may be left behind.

6.5 Land Tenure and Policy Gaps

Secure land ownership is often a precondition for participation in carbon markets. However, many smallholders do not possess formal land titles, which excludes them from benefiting. In addition, policy and regulatory gaps in India and other countries limit the scalability of farmer-led carbon initiatives.

7. Case Studies and Success Stories

Effective deployment of carbon farming and engagement in carbon markets in different nations has proved the economic and environmental advantages of using this strategy. The case studies below illustrate how carbon markets can be used to enhance farm revenues, enhance sustainable agriculture practices, and restore ecosystems. Paul *et.al.* 2013.

7.1 India: EKI Energy and Carbon Farming Projects

EKI Energy Services Ltd., a prominent carbon credit developer company in India, has partnered with farmers in Maharashtra and Madhya Pradesh to adopt climate-smart agricultural practices like biochar application, organic composting, and agroforestry. These methods have assisted in mitigating greenhouse gas emissions while enhancing soil productivity and fertility. Farmers involved have earned an additional ₹2,000–₹6,000 per acre annually through the sale of carbon credits derived through verified means. EKI aggregator model assists smallholders in aggregating their efforts and facilitating certification procedures more conveniently.

7.2 Kenya: Vi Agroforestry Carbon Project

In Kenya, the Vi Agroforestry project enabled more than 30,000 small-scale farmers to adopt agroforestry measures, such as planting trees and landcare. These measures not only added up to better carbon sequestration but also reversed ecosystems and enhanced biodiversity. Farmers had undergone the Plan Vivo certification scheme and had been paid for the carbon credits they produced. The project hugely enhanced rural incomes as well as fostered climate resilience.

7.3 United States: Indigo Ag

In the US, Indigo Ag has led the way with carbon farming initiatives through incentives for farmers to use regenerative agriculture methods including no-till, cover crops, and lower nitrogen inputs. Farmers participating receive payments ranging from $15 to $30 per acre per year, with the credits validated under standards such as the Climate Action Reserve. Such a model has proven to hold potential in integrating technology, sustainability, and profitability.

8. Policy and Institutional Framework

A strong policy and institutional structure is needed to assist farmers in gaining access to carbon markets and to provide credibility, scalability, and long-term sustainability of carbon credit schemes. In recent years, national and global institutions have made significant efforts to evolve frameworks to facilitate carbon trading and farmer engagement.

8.1 India's Position

India has made progressive efforts to synchronize its climate objectives with carbon market mechanisms. The Carbon Credit Trading Scheme (CCTS), as brought in by the Energy Conservation (Amendment) Act, 2022, is the foundation for the official carbon market within the nation. The scheme facilitates the trading of carbon credits and seeks to bring compliance and voluntary sectors into a single system. The government is encouraging voluntary carbon markets where farmers and private sector players can engage and profit from carbon sequestration activities in forestry and agriculture. Olale *et.al.* 2019.

8.2 Government and NGO Role

Government departments and NGOs play a key role in enabling grassroots-level carbon farming. Their functions include:

- Capacity development via training programs and awareness-raising initiatives.
- Enabling carbon aggregators and FPOs (Farmer Producer Organizations) to engage farmers.
- Creating infrastructure and technological support systems for efficient Monitoring, Reporting, and Verification (MRV).

These interventions close the knowledge and accessibility gaps for marginal and small farmers.

8.3 Global Support Mechanisms

Global mechanisms have also intervened to fund and assist carbon market initiatives. The leading players are:

- The Green Climate Fund (GCF), which provides financing for climate-resilient projects.
- World Bank Carbon Funds, which offer financing and technical support for emission reductions.
- The International Emissions Trading Association (IETA), which supports effective carbon pricing and policy.

9. Way Forward and Recommendations

1. Farmer Awareness & Training: Capacity-building initiatives on carbon finance and MRV tools.

2. Low-cost MRV Solutions: Remote sensing, drones, and IoT to lower costs.

3. Incentivizing Aggregators: Support public-private partnership to aggregate smallholders.

4. Transparent Policies: National policy for carbon rights, benefit sharing, and clarity of land tenure.

5. Stable Pricing Mechanism: Minimum floor price or price guarantees to bring down volatility.

10. Conclusion

Carbon markets have huge scope to raise farmers' incomes while also helping mitigate climate change. With proper support systems—policy, technology, and institutional frameworks—India's farmers can be an important element in the carbon economy. Aligning carbon farming with agriculture policies can result in sustainable, equitable, and remunerative farming systems in the next few decades.

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Nature's Ink: Bio-pigment from Flower Petals

Shakila Sadasivam[1], Akshaya S.B[2], Jeyajothi R[3], Akino Asokan[4], Vinothini N[5] and Venkatakrishnan L[6]

[1]Department of Floriculture and Landscape Architecture, [2]Department of Plant Pathology, [3]Department of Agronomy, [4]Department of Fruit Science, [5]Department of Seed Science and Technology, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu District - 603 201, Tamil Nadu, India.

[6]School of Agricultural Sciences, Takshashila University, Villupuram District – 604 305, Tamil Nadu

Introduction: The Colourful Chemistry of Nature

Flowers are not only nature's decorative wonders but also treasure troves of natural compounds. Among these, bio-pigments are gaining attention for their vivid hues and eco-friendly potential. These pigments are responsible for the captivating reds, blues, yellows, and purples we see in blossoms. More than mere aesthetics, these pigments serve biological functions like attracting pollinators, shielding plant tissues from harmful UV radiation, and acting as antioxidants. As sustainability becomes a global imperative, scientists are now exploring flower-derived bio-pigments as replacements for synthetic dyes, which are often toxic and non-biodegradable. The beauty of these natural colours lies not just in their appearance but in their environmentally friendly promise.

Bio-pigments

Bio-pigments are naturally occurring colour compounds produced by plants, algae, and some bacteria. In flowers, they are predominantly secondary metabolites that offer colouration and biological benefits. The major categories of flower bio-pigments include:

1. **Anthocyanins**: These water-soluble pigments are responsible for red, blue, and purple hues in flowers such as pansy, petunia, and butterfly pea. They are sensitive to pH, which causes them to change colour in different environments—an attribute that is useful in food and cosmetic applications.
2. **Carotenoids**: These fat-soluble pigments yield yellow, orange, and red colours and are abundant in marigolds, calendula, and sunflowers. Apart from colour, carotenoids like lutein and zeaxanthin are known for their health benefits, especially in eye health.
3. **Betalains**: These are nitrogen-containing pigments found in plants like bougainvillea and cacti. They offer vibrant red and yellow hues and are prized for their antioxidant properties.

These pigments are gaining commercial interest due to their natural origin, safety, and multifunctional uses.

Biosynthesis and Plant Function of Pigments

The production of pigments in flowers is a highly regulated process involving multiple enzymatic pathways.

- **Anthocyanins** are synthesised via the flavonoid pathway, beginning with phenylalanine. Key enzymes include chalcone synthase and flavonoid 3'-hydroxylase.
- **Carotenoids** originate from the isoprenoid biosynthetic pathway, with precursors like phytoene and lycopene.
- **Betalains** are derived from the amino acid tyrosine and include two types: betacyanins (red-purple) and betaxanthins (yellow-orange).

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These pigments help flowers attract pollinators like bees and butterflies, contributing to reproductive success. Additionally, their antioxidant properties help mitigate oxidative stress caused by environmental conditions such as UV radiation and pathogen attack.

Extraction of pigments from flowers

Traditional chemical extraction methods often involve harmful solvents. In contrast, modern eco-friendly techniques include:

- **Aqueous and Alcoholic Extraction**: This method uses water or ethanol to dissolve water-soluble pigments like anthocyanins. It is simple and ideal for food-grade applications.
- **Enzyme-Assisted Extraction**: Enzymes like cellulase and pectinase are used to break down cell walls, thereby releasing pigments efficiently.
- **Ultrasound-Assisted Extraction (UAE)**: This method uses ultrasonic waves to disrupt plant tissues, increasing yield and reducing extraction time.
- **Microwave-Assisted Extraction (MAE)**: Microwaves generate internal heating within plant cells, enabling quicker and cleaner extraction.
- **Supercritical Fluid Extraction**: This advanced technique uses supercritical CO_2 as a solvent. It is non-toxic, recyclable, and highly efficient in extracting carotenoids.

Major sources of Bio-Pigments

Flower	**Dominant Pigment Class**	**Example Shade**	**Key Industrial Use**
Hibiscus (*Hibiscus rosa-sinensis*)	Anthocyanins	Deep crimson to magenta	Beverage colourant, cosmetics
Butterfly Pea (*Clitoria ternatea*)	Anthocyanins (ternatins)	Vivid blue	pH-sensitive food dye, beverages
Rose Petals (*Rosa* spp.)	Anthocyanins	Pink to red	Natural cosmetics, gourmet foods
Marigold (*Tagetes erecta*)	Carotenoids (lutein)	Golden yellow	Poultry feed, textile dye
Calendula (*Calendula officinalis*)	Carotenoids	Bright orange	Medicinal ointments, textiles
Sunflower Petals (*Helianthus annuus*)	Carotenoids	Yellow	Food colouring, nutraceuticals
Bougainvillea bracts (*Bougainvillea* spp.)	Betalains	Magenta, purple	Fabric dye, inks
Celosia (*Celosia cristata*)	Betalains	Magenta, purple	Food colouring, neutraceuticals
Dragon Fruit Flower (*Hylocereus* spp.)	Betacyanins	Red	Functional beverages
Safflower (*Carthamus tinctorius*)	Carthamin (quinochalcone)	Red to yellow	Textile dye, food colouring

Applications of Bio-Pigments

The applications of flower-derived pigments are in various industries such as.

1. **Food Industry**: Natural food colouring is in high demand due to consumer preference for clean labels. For example, butterfly pea flower extract is used in teas and desserts that change colour with pH, offering both aesthetic and functional appeal. Rose and hibiscus extracts are also used in jams, beverages, and gourmet garnishes.
2. **Textile Industry**: The fashion industry is increasingly turning to natural dyes to reduce its environmental footprint. Marigold and hibiscus dyes are used in printing and dyeing fabrics, offering vibrant yet biodegradable alternatives to synthetic dyes. Artisans and eco-fashion brands are reviving traditional dyeing methods using these pigments.
3. **Cosmetics**: Floral pigments are replacing artificial dyes in lipsticks, blushes, and eyeshadows. Their antioxidant properties provide anti-aging and anti-inflammatory benefits. Products formulated with flower pigments also appeal to consumers seeking natural and organic ingredients.
4. **Pharmaceuticals and Nutraceuticals**: Pigments like anthocyanins and carotenoids possess anti-inflammatory, anti-cancer, and vision-enhancing properties. They are being incorporated into dietary supplements and therapeutic formulations. Betalains, for example, have shown promise in reducing oxidative stress and improving liver health.

Sustainability and Circular Economy

The extraction of bio-pigments from flowers supports the concept of a circular economy. Floral waste, often generated in bulk from temples, weddings, and floriculture markets, can be repurposed rather than discarded. This waste can become a source of valuable raw material for dye extraction, creating a win-win situation: reducing environmental burden and generating economic value. Start-ups and community-level enterprises are increasingly tapping into this opportunity. By training local communities to collect and process floral waste, jobs are created and pollution is curtailed. This approach aligns perfectly with the goals of sustainable development. In India, initiatives like 'HelpUsGreen' and municipal collaborations are working toward converting temple flower waste into dyes, incense, and compost.

Future Prospects and Challenges

- **Stability**: Natural pigments often degrade in the presence of light, heat, or oxygen, limiting their shelf life.
- **Standardisation**: Achieving uniform colour quality across batches can be difficult due to variations in flower quality and seasonal changes.
- **Scalability**: While small-scale extraction is feasible, large-scale industrial processes require cost-effective and high-throughput technologies.

Conclusion

Flowers have delighted humans for centuries with their colour, fragrance, and symbolism. Now, their pigments are emerging as sustainable, healthful, and eco-friendly alternatives to synthetic colourants. As industries seek greener choices, bio-pigments from flowers offer a vibrant solution. Harnessing their potential adds value to floral biodiversity and also contributes to a cleaner, more sustainable world. From food and textiles to pharmaceuticals and art, the future of pigments lies in petals. With continued innovation and investment, bio-pigments from flowers could colour a new era, where beauty meets responsibility and sustainability blossoms.

Virtual Water and Water Footprint

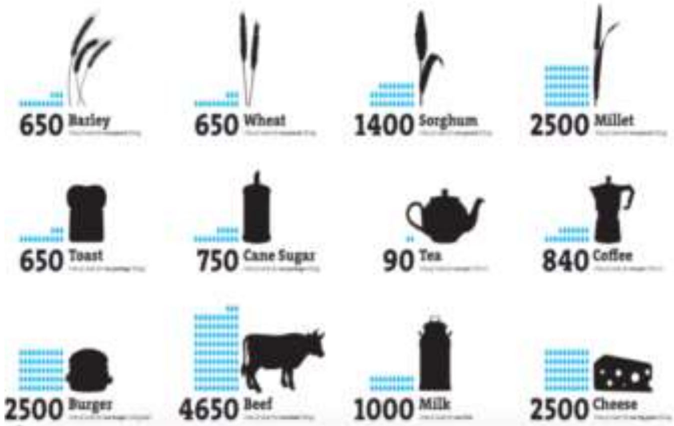
Vinothini N[1], Akino A[2], Jeyajothi R[3], Akshaya S.B[4], Shakila S[5]
Department of Seed Science and Technology[1], Department of Fruit Science[2], Department of Agronomy[3], Department of Plant Pathology[4], Department of Floriculture and Landscape Architecture[5], SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu District - 603 201, Tamil Nadu

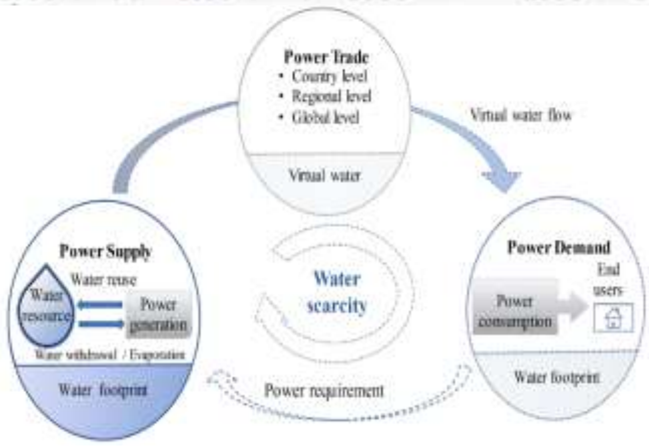
Introduction

Water is an essential natural resource, not only for direct human consumption but also for food production, industrial processes, and ecosystem functioning. With growing concerns about freshwater scarcity and uneven global distribution of water resources, new metrics have emerged to better understand and manage water usage. Among these, the concepts of "virtual water" and "water footprint" have gained prominence. Virtual water refers to the amount of water embedded in products during their production, especially in agriculture and industry, while water footprint accounts for the total volume of freshwater used directly and indirectly by an individual, community, business, or nation. These concepts allow stakeholders to assess and reduce water use more holistically, highlighting the hidden flows of water involved in global trade and production.

1. Concept of Virtual Water

Virtual water is the volume of water required to produce a product or service, encompassing all stages of the supply chain. The term was introduced by John Anthony Allan in the early 1990s to illustrate how water-scarce countries could import water-intensive products rather than depleting their limited freshwater resources. For instance, producing 1 kilogram of wheat requires around 1,500 liters of water, and this water becomes virtually embedded in the wheat. When this wheat is exported, the water used is effectively transferred, highlighting the unseen dimension of global water distribution.





Types of Water Footprint

The water footprint is a multidimensional indicator that measures the total volume of freshwater used to produce goods and services consumed by individuals or groups. It is broadly categorized into three components:

- ***Blue Water Footprint:*** Refers to the consumption of surface and groundwater resources (e.g., irrigation, industrial use).
- ***Green Water Footprint:*** Represents the usage of rainwater stored in the soil and used by plants (mainly relevant in agriculture).

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- ***Grey Water Footprint:*** The volume of freshwater required assimilating pollutants and maintaining water quality standards.

2. Virtual Water in Agriculture and Trade

Agriculture is the largest consumer of freshwater globally, making virtual water particularly relevant in this sector. Crops such as rice, cotton, and sugarcane are highly water-intensive. By importing such crops, water-scarce countries can conserve their internal water resources. This trade in virtual water has implications for food security, economic policies, and environmental sustainability. For example, countries like Saudi Arabia have shifted from local wheat production to importing wheat, effectively importing virtual water to preserve their scarce water resources.

3. Water Footprint Assessment Methods

Assessing water footprints involves detailed accounting of water inputs throughout the life cycle of a product or activity. The Water Footprint Network (WFN) has developed standardized methodologies for conducting water footprint assessments. These include:

- Inventory Analysis: Tracking water use at each stage of production.
- Impact Assessment: Evaluating environmental consequences of water use.
- Geographic and Temporal Scales: Considering spatial and seasonal variations in water availability and use.

These assessments help businesses, farmers, and policymakers identify hotspots of water use and potential areas for efficiency improvements.

Applications of Virtual Water and Water Footprint

- Understanding virtual water and water footprints can aid in:
- Policy Making: Informing water-saving strategies and trade policies.
- Corporate Sustainability: Helping businesses identify and reduce their water use.
- Consumer Awareness: Educating individuals about the hidden water costs of their consumption patterns.

Irrigation Planning: Optimizing water use in agriculture based on crop water requirements and regional water availability.

Conclusion

The concepts of virtual water and water footprint provide a powerful framework for understanding and managing global water use. They shift the focus from local consumption to global interdependencies, urging nations, industries, and individuals to recognize their indirect water consumption and make informed decisions. As the world grapples with water scarcity, incorporating these insights into planning and policy will be essential for sustainable development.

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Pathogenic Fungi in *Aloe barbadensis*: Current Insights and Sustainable Disease Management Approaches

Krishna Kumar, Uzma Manzoor and Sahadeva Singh

School of Agriculture, Galgotias University, Greater Noida-201310, UP, India

Introduction

Commonly referred to as aloe vera, *Aloe barbadensis* is a succulent plant with substantial medicinal and commercial value that is frequently used in nutraceuticals, cosmetics, and medicines. Anthraquinones, polysaccharides, and flavonoids are some of its bioactive substances that have strong antibacterial, anti-inflammatory, and antioxidant qualities. But because of its quick commercial growth, it is now more susceptible to fungal infections, which have a negative influence on yield, quality, and market value. As serious dangers, pathogenic fungi like *Fusarium oxysporum, Curvularia lunata*, *Colletotrichum boninense*, and *Alternaria alternata* have been found to cause diseases like brown spot, anthracnose, root rot, and leaf spot. In addition to endangering the plant's health, these diseases lessen the gel's therapeutic qualities. In order to maintain the long-term sustainability of aloe cultivation, this review examines recent findings regarding the identification, epidemiology, and pathogenicity of fungal infections in *Aloe barbadensis*. It places particular emphasis on sustainable disease management strategies, such as biological control, cultural practices, and molecular diagnostics.

The Rise of *Aloe barbadensis* and Disease Susceptibility

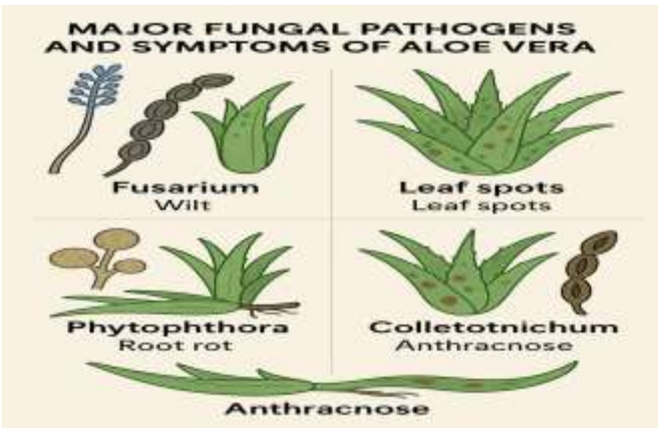
A succulent plant that thrives in dry environments, *Aloe barbadensis* is widely grown in Asia, Africa, and the Americas. With more than 200 bioactive components, such as flavonoids, glucomannans, and anthraquinones, it is a mainstay of complementary and alternative medicine. Pandey and Singh (2016) estimate that the growing demand for natural health solutions has made the global market for aloe-based products worth over $110 billion.

Large-scale monoculture and insufficient disease monitoring, however, have made people more susceptible to fungal infections. In Yuanjiang County, Yunnan Province, China, the fungal environment influencing *Aloe barbadensis* plantations was studied in a significant study by Zhang et al. (2025). Through field surveys, pathogen isolation, and DNA sequencing, the researchers identified four major fungal diseases: root and leaf rot caused by *Fusarium oxysporum*, leaf spot by *Curvularia lunata*, anthracnose by *Colletotrichum boninense*, and brown spot disease by *Alternaria alternata*.

Major Fungal Pathogens and Symptoms

1. **Root and Leaf Rot (*Fusarium oxysporum*)**

This disease damages roots and spreads to leaves, especially during June. Roots develop black lesions from the center outward, leading to extensive decay. Affected leaves show semi-circular gray-black lesions at the margins. The pathogen's macroconidia are sickle-shaped and exhibit 1-3 septa.



2. **Leaf Spot (*Curvularia lunata*)**

Occurring primarily in the summer, this disease manifests as small, sunken, black elliptical spots on leaves. As it progresses, lesions coalesce into larger brown spots. *Curvularia lunata* spores are curved, three-septate, and brown with paler end cells.

3. **Anthracnose (*Colletotrichum boninense*)**

Symptoms include necrotic leaf spots and yellow halos. This disease is common in warm, humid conditions and can devastate commercial crops if untreated.

4. **Brown Spot (*Alternaria alternata*)**

This fungus causes dark necrotic spots, typically on the leaf tips, and leads to substantial quality loss. Mishra (2022) highlighted that the disease flourishes in high humidity (65-95%) and temperatures between 23-28°C. The pathogen survives for up to ten months, serving as a recurring source of infection.

Disease Management Strategies

The ecological risks of synthetic fungicides, researchers emphasize environmentally sustainable disease control methods. Biological control agents such as *Cladosporium herbarum*, *Trichoderma* spp., and *Aeurobasidium pullulans* have demonstrated antagonistic effects against *Alternaria alternata* and other pathogens. These agents inhibit fungal growth through competition, parasitism, and secondary metabolite production.

Disease incidence can be decreased by cultural measures like crop rotation, disease removal, and better drainage. According to Mishra (2022), for example, the illness is more common in areas that are prone to cold or poor drainage, where stress weakens the plants.

Timely intervention and accurate diagnosis are made possible by molecular methods for pathogen identification, as the ITS-based DNA sequencing employed by Zhang et al. (2025). Selecting resistant plant cultivars and assessing virulence are further aided by pathogenicity testing using standardized spore suspensions.

Economic and Industrial Implications

The effectiveness of the gel in medications and cosmetics is directly impacted by fungal infections, which lower the biomass and biochemical integrity of aloe leaves. Specifically, Alternaria infections reduce glycoprotein content and antibacterial potential. Consumer confidence is impacted, and the rising aloe business is at risk, especially in places like China and India where production is strong and processing infrastructure is growing.

According to Pandey and Singh (2016), consistent quality testing is urgently needed to ensure product reliability and regulatory compliance. Protecting aloe cultivation with integrated pest management (IPM) is crucial as the plant continues to gain popularity in functional meals and supplements.

Conclusion

Aloe barbadensis cultivation and industrial value are seriously threatened by fungal infections. The foundation for well-informed illness management has been established by extensive research, which includes pathogen identification and symptom characterization. A possible way forward is provided by the combination of molecular diagnostics, cultural behaviors, and biological regulation. Aloe agriculture will become more sustainable with continued study, especially on disease-resistant cultivars and environmental triggers, ensuring the survival of this essential plant resource.

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Microplastic in Agricultural Soil: Understanding the Entry Pathways

Ghanashyam Singh Yurembam[1], Bidyarani Chanu[1], Saya D[1], D. Jhajharia[1]
[1]Department of Soil and Water Conservation Engineering, CAEPHT, Ranipool, Sikkim

Introduction

Plastics are widely used in everyday life today due to their affordability and durability. According to the latest data from Plastic Europe, global plastic production reached 413.8 million tonnes in 2023 (**Plastics Europe, 2024**). Unfortunately, only a small fraction of this plastic is recycled. Improper disposal has led to the accumulation of over 4.9 billion tonnes of plastic waste in the environment (**Geyer *et al.,* 2017**). Contamination from plastics, particularly in the microplastic (MPs) size range (1 µm–5 mm), has become a significant environmental issue for the biosphere and a growing global concern. While the presence of MPs in marine environments has received considerable attention, recent studies suggest that terrestrial systems, especially soils, may contain even higher concentrations of MPs (**Rillig *et al.,* 2017**; **Machado *et al.,* 2018**). This pollution in terrestrial environments is particularly alarming due to its direct impacts on food production, soil biodiversity, and the potential for MPs to enter the food web through crops. Smaller MPs particles in soil, especially those with high bioavailability, are more likely to be ingested and absorbed by animals and plants.

This article focuses on the pathways through which MPs, primarily polyethylene (PE), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polypropylene (PP), and polystyrene (PS), enter soil systems. MPs can infiltrate various environmental compartments through multiple pathways, which can be broadly categorized into direct and indirect pathways. Understanding these entry points is essential for assessing the environmental fate of MPs, evaluating their ecological risks, and exploring their implications for soil health and food safety (**Rillig & Lehmann, 2020**). MPs also act as carriers for many hydrophobic organic contaminants and heavy metals. The specific pathway (Figure 1) and ultimate fate of plastic particles in soil systems are influenced by a combination of environmental conditions and human activities.

Figure 1: Pathways of microplastic contamination in agriculture soil

1. Direct pathways

These include the application of plastic mulching films, greenhouse coverings, sewage sludge, compost and organic fertilizers, and irrigation with contaminated water. While these practices are beneficial for crop productivity, they inadvertently increase the risk of MPs accumulation in agricultural soils.

- **Plastic mulching films:** Plastic mulching is widely used in agriculture for moisture retention, weed control, and temperature regulation. However, after use, waste plastic residues from these mulching practices often remain in the soil.

These residues gradually degrade into smaller fragments through various physical, chemical, and biological processes in the soil environment, ultimately forming MPs. This transformation occurs due to factors such as ultraviolet (UV) radiation, water and wind erosion, and biological activity including the action of soil fauna like earthworms **(Steinmetz *et al.,* 2016)**. Additionally, photo-oxidative degradation accelerates the fragmentation of plastics into even finer particles. As a result, agriculture has become one of the most heavily impacted sectors in terms of soil MPs contamination.

- **Greenhouse Cover:** Greenhouse coverings, typically made from plastic materials such as polyethylene (PE), polyvinyl chloride (PVC), or polycarbonate (PC), are essential for protecting crops and regulating environmental conditions. Continuous exposure to sunlight, wind, rain, and temperature fluctuations causes the plastic films to degrade through photodegradation and physical wear **(Qi *et al.,* 2020)**. This degradation results in the release of MPs particles into the surrounding soil and air. Additionally, these plastics often contain chemical additives such as plasticizers, UV stabilizers, and flame retardants, which can leach into the environment and pose risks to soil health, plant growth, and even food safety.

- **Sewage Sludge Application:** Sewage sludge is widely applied to agricultural soils across the globe as a fertilizer due to its high content of organic matter and essential macro- and micronutrients, which enhance soil fertility and overall function **(Ramage *et al.,* 2025)**. However, this practice also contributes to the accumulation of MPs in the receiving soils. As the application of sewage sludge is expected to continue, it may lead to a progressive build-up of MPs over time. Nonetheless, MPs are not currently included among the regulated constituents of sewage sludge.

- **Compost and Organic Fertilizers:** In recent years, the application of compost and organic fertilizers has become as a notable pathway for MPs to enter the soil environment. Organic fertilizers, made from composted organic waste, are becoming an important input that helps promote sustainable farming by reusing waste materials **(Li *et al.,* 2024)**. However, a growing concern is the substantial presence of plastics within this process. Numerous studies have reported the widespread detection of MPs in organic fertilizers, highlighting them as a significant and often overlooked contributor to soil MPs contamination.

- **Treated Wastewater Irrigation:** Agricultural sustainability is facing growing challenges due to climate change, water shortage, shrinking farmland, and poor soil health. With clean water becoming less available, many farmers are using treated or untreated wastewater for irrigation because it contains useful nutrients **(Pérez-Reverón *et al.,* 2020)**. However, this water often carries MPs, which are not fully removed by treatment plants. As a result, MPs enter the soil through irrigation and the use of sewage sludge. Over time, this can cause a buildup of MPs in the soil, harming soil quality, crop growth, and long-term farming sustainability.

2. Indirect Pathways

MPs can enter agricultural soils through various indirect routes, primarily influenced by environmental processes involve atmospheric deposition, surface runoff, flooding and soil erosion.

- **Atmospheric Deposition through rainfall:** Rainfall plays a significant role in the atmospheric deposition of MPs onto soil surfaces. As MPs become suspended in the air through wind, human activities, or industrial emissions, they can be carried over long distances **(Dris *et al.,* 2016)**. When it rains, these airborne MPs are captured by raindrops and deposited onto the

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ground, including agricultural fields. This process allows microplastics to enter soil ecosystems even in remote or rural areas, far from the original pollution sources. Over time, repeated rainfall events contribute to the accumulation of MPs in the soil, potentially affecting soil structure, fertility, and plant health.

- **Surface runoff: It** plays a significant role as an indirect pathway for the transport and redistribution of MPs into soil environments **(Zhang *et al.,* 2024)**. When rainfall or snowmelt occurs, water flows over land surfaces, collecting and carrying various pollutants, including MPs particles. These MPs originate from urban areas such as tire wear particles, synthetic fibers from washing clothes, plastic debris on roads and rooftops and from industrial zones where plastic pellets or manufacturing residues may be present. As runoff water moves across these surfaces, it picks up MPs and transports them into surrounding environments, including agricultural fields, drainage systems, and natural water bodies.
- **Flooding and soil erosion:** Floods are increasingly recognized as one of the major driving forces in the environmental cycling of plastics. These events intensify the erosion of riverbeds and riverbanks, significantly influencing the re-mobilisation and subsequent deposition of MPs **(Rolf *et al.*, 2022)**. Many studies on erosion have shown that MPs exhibit greater mobility compared to natural river sediments. More recently, research has focused on the role of floods in transporting MPs into floodplains and their eventual incorporation into floodplain soils and agricultural fields.

Conclusion

Microplastic (MPs) contamination in agricultural soils arises through both direct (plastic mulching, sewage sludge, compost) and indirect (atmospheric deposition, runoff, flooding) pathways. These MPs not only persist in soil but also pose risks to soil health, crop productivity, and food safety due to their potential to carry harmful contaminants. Tackling this issue requires better waste management, stricter agricultural regulations, biodegradable alternatives, and continued research to support effective mitigation and ensure sustainable soil and food systems.

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Soil Microorganisms and Their Role in Natural Farming

[1]Aaina Sharma, [2]Janga Prasanth, [3]Chinmoy Deori, [4]Anil Kumar

[1]Assistant Professor, Department of Agriculture, Maharishi Markandeshwar (Deemed to be University) Mullana, Ambala -133207

[2]Farm Manager (Programme Assistant), Dept of Microbiology Krishi vigyan Kendra, Nellore, Acharya N.G. Ranga Agricultural University Guntur, Andhra Pradesh-524004

[3]SMS (Agronomy), KVK Sribhumi, Assam

[4]Assistant Professor, Department of Agronomy, School of Agriculture, Eklavya University Damoh, M.P

Soil microbes have a central role to play in maintaining soil fertility, nutrient cycling, and plant health and are therefore a key part of natural farming systems. These are bacteria, fungi, actinomycetes, algae, and protozoa, which all contribute to enhanced availability of nutrients, disease suppression, and better structure. Natural farming methods such as Jeevamrit, Beejamrit, and composting depend on these microbes for sustainable production of crops without the use of chemical inputs. Through the utilization of beneficial microbes, natural farming also boosts the health of soil, the resilience of crops, and sustainable agriculture. Improved research, farmer education, and policy support can also help to hasten the implementation of microbe-based natural farming systems.

2. Introduction

Soil microorganisms are critical constituents of the soil ecosystem, having a core role in ensuring soil fertility, health, and sustainable agricultural productivity. These small microorganisms such as bacteria, fungi, actinomycetes, algae, and protozoa are engaged in critical biological processes like nutrient cycling, decomposition of organic matter, nitrogen fixation, and disease suppression. Their activity and existence have profound impacts on the physical, chemical, and biological characteristics of the soil.

Natural farming, an ecological and chemical-free farming system, is based to a large extent upon the activities of soil microorganisms for ensuring soil fertility and crop productivity. In contrast to the synthetic fertilizer and pesticide-dependent conventional farming, natural farming encourages the application of native microbial-rich preparations such as Jeevamrit, Beejamrit, and compost to feed and stimulate the native soil life. These preparations induce an increase in microbial activity, which further facilitates increased nutrient transformation, improves the health of the plants, and improves resistance to pests and diseases. Bhagat *et al.* 2024.

Soil microorganisms are natural biofertilizers and biopesticides in the case of sustainable agriculture. Synergistic action with roots results in increased nutrient uptake and healthy growth of plants without environmental damage. Hence, the role of soil microorganisms in the success of natural farming systems, ensuring both food security and ecological balance, is crucial.

2.1 What Are Soil Microorganisms?

Soil microorganisms are small living organisms that live in the soil and are fundamental to soil fertility and plant health. They consist of bacteria, fungi, actinomycetes, protozoa, and algae. They are the pillars of the soil ecosystem, conducting essential biochemical activities.

2.2 What is Natural Farming?

Natural farming is an ecological, chemical-free agricultural method that involves utilization of natural inputs such as crop residues, animal dung/urine, vegetable decoctions, and microbial

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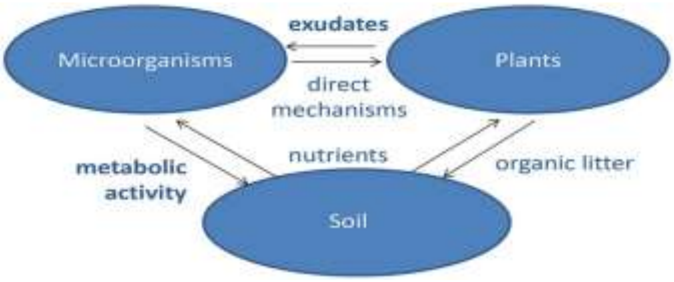
preparations like Jeevamrit and Beejamrit. It depends drastically upon microbial processes to maintain soil fertility and crop yield. Devarinti *et.al.* 2016.



Sources: https://www.frontiersin.org/

3. Types of Soil Microorganisms

Understanding Microbial Diversity in Natural Farming

Soil is inhabited by a rich and diverse population of microorganisms that work behind the scenes to maintain plant and soil health. These microorganisms are the basis of nutrient cycling and are key to the success of natural farming systems.

3.1 Bacteria

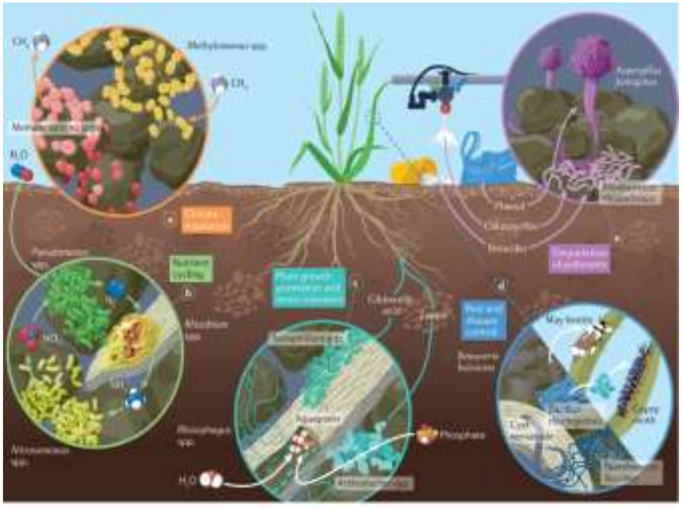
Bacteria are the most dominant microbes in the soil. They carry out critical processes like nitrogen fixation (Rhizobium, Azotobacter), organic matter decomposition, and phosphate solubilization (Bacillus, Pseudomonas). In nature-based farming, bacteria brought in by Jeevamrit are responsible for mobilizing nutrients, promoting plant growth, and sustaining soil fertility.

3.2 Fungi

Fungi are decomposers that degrade complex organic substances such as lignin and cellulose. Nonsym pathogenic fungi such as Trichoderma and Aspergillus inhibit soil-borne diseases, and mycorrhizal fungi set up symbiotic relationships with plant roots, increasing phosphorus uptake and soil structure and water-holding capacity—essential in organic systems.

3.3Actinomycetes

These are filamentous bacteria, like fungi, that break down difficult-to-biodegrade organic compounds. Streptomyces species are also responsible for producing natural antibiotics, serving to repress dangerous pathogens. They are also involved in composting and soil microbiome enrichments.



Source: https://www.nature.com

3.4 Algae and Cyanobacteria

Photosynthetic microbes such as Anabaena, Nostoc, and Chlorella have the ability to fix nitrogen from the atmosphere and are found abundantly in paddy fields. Their growth increases soil fertility and is utilized in biofertilizer preparation employed in natural agriculture.

3.5 Protozoa

Protozoa like Amoeba and Ciliates consume bacteria, controlling microbial populations and making available nutrients like nitrogen in a form utilizable by plants. They ensure microbial balance and nutrient cycling in the rhizosphere.

Together, these microbes maintain soil health and are the driving force behind natural farming and regenerative farming practices.

4.Soil Microorganisms' Role in Natural Farming

The Driving Force of Soil Health and Plant Growth

Soil microbes are the building blocks of natural farming. Their ever-changing activities enrich the soil, promote plant well-being, and lower the demand for man-made inputs. Some of the major roles played by soil microbes in natural ecosystems include: Liao *et.al*. 2019.

4.1 Nutrient Cycling

Soil microorganisms decompose complicated organic materials—like crop residues, animal excreta, and green manure—into simpler substances. In the process of decomposition, the nutrients nitrogen (N), phosphorus (P), and potassium (K) are released in a form that can be utilized by plants. This process creates a steady supply of nutrients in natural agricultural systems.

4.2 Biological Nitrogen Fixation

Some of these bacteria like Rhizobium, Azospirillum, and actinomycetes such as Frankia can fix atmospheric nitrogen into ammonia, a form available to plants. This activity largely eliminates the use of chemical nitrogen fertilizers, particularly in leguminous plants.

4.3 Phosphate Solubilization

Microbes such as Pseudomonas and Aspergillus break down insoluble phosphate into soluble ones, making them available to plants. This solubilization is natural and decreases the dependence on chemically processed and externally mined phosphorus fertilizers.

4.4 Disease Suppression

Favorable microbes suppress the growth of destructive pathogens by:

- Antibiosis – the release of antibiotics that kill pathogens.
- Parasitism – directly killing and feeding on destructive organisms.
- Competition – competing with pathogens for space and nutrients.

4.5 Improvement in Soil Structure

Fungi and bacteria secrete glomalin and other organic molecules that assist in binding soil particles in the form of aggregates. This enhances soil structure, improves aeration and porosity, and increases the water-holding capacity of soil—vital for drought resistance and soil-conserving agriculture.

These roles combined render microorganisms essential for use in natural farming in providing a healthy, self-maintaining agro-ecosystem.

5. Microbial Inputs in Natural Farming

Natural Soil Life and Plant Growth Boosters

Microbial inputs form the core of natural farming systems. They promote microbial counts in the soil, enhance nutrient availability, and promote plant immunity without the application of chemical inputs. These bio-inputs are cost-effective, locally produced, and eco-friendly. Goh *et.al.*2003.

5.1 Jeevamrit

Jeevamrit is a liquid microbe-rich fermented product that works as an excellent bio-stimulant for soil and crops. It is made from cow dung, cow urine, jaggery, pulse flour, and a small amount of farm soil. Jeevamrit encourages the growth of beneficial microbes and increases the breakdown of organic matter. Frequent application enhances mobilization of nutrients and increases crop yields. It is commonly sprayed on crops or irrigated.

5.2 Beejamrit

Beejamrit is an organic seed treatment formula that is applied to seeds to guard them against soil-borne diseases. Beejamrit is prepared from cow dung, cow urine, lime, and field soil. Beejamrit-coated seeds have improved germination, improved root growth, and natural resistance to disease in the initial growing period. It forms a microbial protection cover around the seed.

5.3 Ghan Jeevamrit

Ghan Jeevamrit is the solid or dry version of Jeevamrit. It is very useful for dry land agriculture or where liquid application is impossible. When used close to the root zone, it enhances soil microbial biomass, increases organic carbon content, and ensures ongoing nutrient cycling.

5.4 Compost and Vermicompost

Both vermicompost and compost are high in microorganisms and organic matter, both beneficial. They enhance the structure of the soil, water holding capacity, and microbial population. They act as slow-release nutrients, promoting continuous plant growth and long-term soil fertility.

6. Benefits of Soil Microorganisms in Natural Farming

Microbial Allies for a Sustainable Agroecosystem

Soil microorganisms are key contributors to the success of natural farming by performing essential ecological services. Their diverse functions not only boost plant growth but also restore soil health, reduce environmental impact, and ensure long-term sustainability.

Benefits at a Glance

Aspect	Contribution of Microorganisms
Soil Fertility	Enhance nutrient cycling, improve organic matter decomposition, and enrich soil microbial biomass.
Crop Productivity	Promote healthy root development and improve nutrient and water uptake.
Sustainability	Minimize the use of synthetic fertilizers and pesticides; foster self-sustaining farming systems.
Pest & Disease Management	Suppress harmful pathogens through competition, antibiosis, and predation.
Climate Resilience	Increase soil organic carbon, improve structure, and enhance moisture retention.

Soil microbes act as natural biofertilizers, biopesticides, and soil conditioners, playing an essential role in regenerative agriculture.

Case Study: Success in Maharashtra

Farmers practicing Subhash Palekar's Zero Budget Natural Farming (ZBNF) in Maharashtra have demonstrated the effectiveness of microbial-based inputs:

- **Yield Increase**: A noticeable 25–30% rise in yields of pulses and cereals, especially in rainfed conditions.
- **Soil Health**: After just two cropping seasons of applying *Jeevamrit*, soils showed better texture, higher microbial activity, and improved moisture retention.

Cost Savings: Reduction in expenditure on chemical fertilizers and pesticides, leading to better net returns.

7. Future Prospects and Recommendations

Strengthening the Foundation of Microbial-Based Natural Farming

The future of sustainable agriculture lies in the revival and amplification of soil biological activity. Microorganisms are key agents in this transformation, and their role in natural farming must be strategically supported through innovation, education, and policy. Srivastava *et.al.* 2003.

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7.1 Research and Innovation

To enhance the effectiveness of natural farming, focused research is required to develop **microbial consortia** that are tailored to specific crops and agro-climatic zones. These consortia can combine nitrogen-fixers, phosphate solubilizers, and biocontrol agents for maximum benefit. Moreover, emphasis should be placed on identifying and **promoting indigenous microbial strains** that are well-adapted to local soils, thereby improving reliability and resilience under field conditions.

7.2 Farmer Awareness and Training

The successful adoption of microbial inputs depends on farmer knowledge and confidence. Therefore, **capacity-building programs**, including hands-on workshops, field demonstrations, and village-level training camps, must be organized to teach the preparation and application of *Jeevamrit*, *Beejamrit*, compost, and other natural inputs. Additionally, **farmer-to-farmer learning models** should be promoted, where experienced natural farmers mentor others, encouraging widespread adoption through trust and practical examples.

7.3 Policy Support

Government support is crucial in scaling microbial-based farming. Policies should **incentivize on-farm production** of microbial inputs and **reduce reliance on synthetic fertilizers** by offering subsidies for composting units and natural input kits. Furthermore, schemes like **Paramparagat Krishi Vikas Yojana (PKVY)** should actively integrate microbial farming practices into their framework, ensuring consistent funding, monitoring, and technical support.

8. Conclusion

Soil microorganisms are the unseen laborers of natural farming, performing vital ecosystem services that sustain agriculture without harming nature. Emphasizing their role through eco-friendly practices like Jeevamrit and compost not only regenerates the soil but also revives the spirit of traditional Indian farming.

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Constraints in biochar adoption and practical recommendations for improvement

Halesh, D. S[1]. and Pooja, V.[2]

[1]Senior Research Fellow, Department of Soil Science and Agricultural Chemistry, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shimoga, Karnataka

[2]Ph.D. Scholar, Department of Agriculture Extension, College of Agriculture, University of Agricultural Sciences, Bangalore, Karnataka

A carbon-rich byproduct of pyrolyzing biomass, biochar has great potential to improve crop productivity, mitigate climate change, and improve soil health. The broad use of biochar in agriculture is hampered by a number of factors, despite its many advantages. Lack of standardized production and application guidelines, high initial production costs, inconsistent quality due to a variety of feedstocks, low policy support, and low farmer awareness are some of the main obstacles. Its incorporation into conventional farming methods is further hampered by the lack of market incentives and weak research-extension ties. A multifaceted strategy is necessary to get past these obstacles. Programs to increase farmer capacity, the creation of quality control standards, the integration of policies with climate-smart agriculture initiatives, financial incentives for the use of biochar, and the encouragement of decentralized biochar production units are all included in this. The sustainable adoption of biochar can be further facilitated by fostering public-private partnerships and fortifying research-extension-farmer ties. To fully utilize biochar for sustainable agricultural development, these limitations must be addressed using realistic and situation-specific approaches.

Introduction

In the present-day context, India produces billions of tonnes of crops. Its contribution goes to the Green Revolution, which has transformed the country from food-deficient to self-sufficient (ICAR, 2021). However, this success leaves behind massive quantities of crop residues like rice husk, pigeon-pea stalks, maize cobs, and cotton stalks, *etc,* which are often burned in fields, releasing smoke and CO_2 and exacerbating climate change (Gatmal *et.al.,*2024). One of the promising solution to this issue is converting these residues into biochar: a carbon-rich byproduct made through pyrolysis, thermally treating biomass in low or no oxygen (Lehmann & Joseph, 2015). Biochar stabilizes carbon for long-term storage in soil and offers environmental, agronomic, and climate benefits (Jeffery *et al.,* 2011).

Challenges in adoption of crop residues management

Despite the promising benefits of biochar in crop residue management and pollution control, several constraints limit its widespread adoption. The major challenges are mentioned below

Lack of awareness and technical knowledge among farmers about biochar production and its application. Many farmers continue to burn residues due to the absence of accessible and affordable alternatives (Gatmal *et.al.,*2024).

High initial costs of setting up pyrolysis units and the lack of decentralized infrastructure for biochar production make it difficult for small and marginal farmers to adopt this technology (Lehmann & Joseph, 2015).Additionally, **Variability in biochar quality** due to differences in feedstock and production methods can affect its performance in soil, creating uncertainty among users (Jeffery *et al.,* 2011; Singh *et al.,* 2022). The **absence of clear policy support, subsidies, and market incentives** for biochar further hinders its implementation.

Furthermore, there are limited **scientific guidelines and field-level data** available to standardize biochar use across different soil and crop types. Transport and handling of bulky crop residues also pose logistical challenges. Overcoming these constraints requires integrated efforts involving research, farmer training, financial support, and strong policy frameworks to promote biochar as a sustainable solution for residue management and pollution control.

Strategies for Overcoming Challenges in Crop Residue Management and Pollution Mitigation through Biochar

To effectively utilize biochar for crop residue management and pollution mitigation, a combination of technical, financial, institutional, and policy-level strategies must be adopted:

- **Farmer Awareness and Capacity Building:** Conducting awareness campaigns, field demonstrations, and hands-on training programs can educate farmers on the benefits of biochar, its production, and application methods. Inclusion of biochar in agricultural extension services will further support adoption at the grassroots level (ICAR, 2021).
- **Affordable and Scalable Technologies:** Developing and promoting low-cost, farm-scale pyrolysis units suitable for small and marginal farmers can make biochar production accessible. Modular and mobile units can help in regions with scattered biomass availability (Lehmann & Joseph, 2015; Singh *et al.,* 2022).
- **Financial Support and Incentives:** Government subsidies, incentives, or carbon credit schemes can reduce the economic burden of setting up pyrolysis systems. Providing financial support through public-private partnerships (PPPs) can accelerate biochar adoption (World Bank, 2021).
- **Policy Support and Integration:** Integrating biochar into national and state-level agricultural and environmental policies—such as residue burning bans, soil health initiatives, and climate action plans—can promote its use. Inclusion of biochar in carbon farming and regenerative agriculture frameworks is also vital.
- **Standardization and Quality Control:** Establishing guidelines and quality standards for biochar production and application based on feedstock type and soil requirements can help ensure consistent results and build farmer confidence.
- **Research and Development:** Encouraging interdisciplinary research on biochar's long-term effects on soil, crop yield, and environment across different agro-climatic zones can help generate location-specific recommendations (Woolf *et al.,* 2010).
- **Efficient Biomass Collection and Supply Chains:** Developing decentralized collection centers and transport logistics for crop residues can ensure a continuous and cost-effective feedstock supply for biochar production (FAO, 2020).
- **Market Development:** Promoting biochar-based products (e.g., soil conditioners, carbon credits) and creating a market linkage can make biochar economically viable and attractive for farmers and entrepreneurs (Lehmann & Joseph, 2015).

By implementing these strategies, biochar can become a practical and sustainable tool for managing crop residues, reducing pollution, and promoting climate-resilient agriculture.

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Case study of successful managemet of crop residues and pollution through biochar

Punjab Agriculture University & Farmer Cooperatives introduced biochar production units in selected villages of Ludhiana and Patiala districts. Farmers were trained to use portable pyrolysis units to convert paddy straw into biochar instead of burning it. Bioenergy potential from crop residue biomass in India.

Conclusion

A promising approach to soil improvement, climate change mitigation, and sustainable crop residue management is biochar. Limited farmer awareness, high upfront costs, a lack of technical infrastructure, inconsistent biochar quality, a lack of supportive policy frameworks, and undeveloped markets are some of the obstacles preventing its widespread adoption in India and other developing nations. These obstacles not only lower the rate of adoption but also restrict the potential large-scale environmental and financial advantages of biochar.

A multifaceted strategy is necessary to close these gaps. Important actions include raising awareness through farmer education and extension services, creating reasonably priced pyrolysis technologies, guaranteeing financial and policy support, standardizing production methods, improving research in various agroclimatic zones, and creating strong biomass supply chains. Additionally, incorporating biochar into national agricultural and climate policies. If all these constraints are targeted and addressed, agricultural sustainability can be maintained with the help of biochar application.

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Harvesting Insights: Role of Data Analytics in transforming agriculture

AKHILA P S
M.Sc. Agricultural Statistics, University of Agricultural Sciences, Dharwad

Agriculture is vital to human survival because it meets basic necessities. There is well known fact that the majority of Indians (≥55%) work in agriculture. Increases in crop output in India are hampered by differences in the country's climate. The three stages of agriculture were traditional agriculture, technologically dynamic agriculture with low capital technology, and technologically dynamic agriculture with high capital technology. Presently, new digital technologies have the power to fundamentally alter conventional farming methods. As the fourth significant agricultural revolution, these developments are commonly referred to as "Agriculture 4.0." According to the World Economic Forum, agriculture will be a part of the "Fourth Industrial Revolution," which will unfold throughout the course of the twenty-first century.

Role of data in agriculture

In agriculture, data refers to the characteristics or variables that farmers require in order to conduct their commercial operations. Specific agricultural records or factors, including crop kinds, yields, soil types in use, and acreage, as well as business-related data, like products, suppliers, customers, and payments, might be included in the data.

Big data is defined using the four dimensions (4 Vs). The massive amount of data being created, saved, and processed is denoted by the first V. The second V stands for the high rates of data generation, collection, and exchange as well as the high speed of data transmission in interactions. According to Sassi et al. (2019), the third V stands for the range of data formats and structures (structured, semi structured, and unstructured) that arise from the diversity of data sources. Veracity, the fourth V, is the capacity to confirm the caliber of the data used in the studies.

In addition to the "4 Vs," Big Data's worth is another aspect that needs to be taken into account. Value is gained by using sophisticated data analysis algorithms and methodologies to uncover hidden patterns, trends, and knowledge models in data. Data science techniques enhance the utility of data by improving knowledge of its behaviors and phenomena, streamlining procedures, and enhancing scientific, business, and machine discoveries. In agriculture, "big data" refers to all of the current technology that is accessible along with data analysis as a foundation for data-only decision-making.

Analyzing big data sets to find patterns, connections, and insights that guide choices is known as data analytics. In order to obtain useful information and support strategic activities, it encompasses a variety of methods and instruments for data analysis and interpretation.

Agriculture data analytics uses cutting-edge technologies and analytical techniques to make conventional farming more productive, efficient, and sustainable. Big data analytics is revolutionizing the agricultural industry by facilitating data-driven decision-making at every stage of the value chain, from the farm to the marketplace. Production has slightly increased as a result of the introduction of technology into the agricultural sector. New ideas like digital agriculture, smart farming, precision agriculture, etc., have been brought forth by the advancements. Designing and implementing sustainable practices can be done with digital agriculture.
agricultural systems at the landscape and farm levels. The goal of digital agriculture is to use data science and information-cum-communication technology to

make farming sustainable and pro table, guaranteeing that everyone can buy wholesome food.

Applications of Big Data analytics in agriculture includes statistical analysis, geospatial analysis, machine learning and artificial intelligence, data mining and blockchain etc. Various types of data analytics applications are utilized in agricultural research for analyzing, visualizing, and interpreting sophisticated datasets to aid decision-making and innovation. GRAPES & RAISINS, ARM (Agriculture Research Management), CropSat, Tableau, Excel, R, Agmatix and Crop Monitoring Platforms (e.g., EOS Crop Monitoring) are some of these.

- Companies like SatAgro use satellite data and machine learning to monitor crop health and recommend actions.
- Syngenta applies big data to breeding programs, analyzing field trial and genetic data to develop better crop varieties.
- Soiltech leverages sensors and analytics for soil health management and yield prediction

Conclusion

The market for agricultural mapping and analytics is expanding rapidly, with particular growth in regions facing environmental stress and those seeking to implement regenerative agriculture practices. North America (USA, Canada) is Among the global leaders in adopting precision agriculture and farm analytics, driven by advanced farm management software, IoT integration, and substantial investments in agri-tech solutions. Data-driven insights can help farmers make better decisions, leading to higher productivity and profitability. Predictive analytics and real-time monitoring help farmers adapt to climate variability and extreme weather, improving stability and food security. Efficiency is increased via the deployment of sensors, agricultural drones, and analytics software. The environmental impact is decreased by better resource management and less excessive chemical use. New market niches are created by consumer demand for eco-friendly products and sustainable farming practices. You can scale production by exporting. Precision farming can benefit from the adaptable solutions provided by the new agriculture entrepreneurs that are just starting out.

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Water-Saving Irrigation Techniques in Agriculture

[2]Dr. Harishankar*, [2]Dr. Dileep Kumar Gupta, [3]Chinmoy deori, [4]Dr. Anil Kumar, [5]Titus Dalang K Momin

[1]Assistant Professor (Agronomy), Institute Name - College of Agriculture and Research Station, Jashpur (C.G.) Pin Code -496225,

[2]Teaching Assistant, Deptt. of Agricultural Extension, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.) - 284128

[3]SMS (Agronomy), KVK Sribhumi, Assam

[4]Assistant Professor, Department of Agronomy, School of Agriculture, Eklavya University Damoh, Madhya Pradesh-470661

[5]SRF, NICRA KVK SGH, Krishi Vigyan Kendra, South Garo Hills Meghalaya

Water-conserving irrigation methods play a critical role in ensuring sustainable agricultural growth, particularly in water-deficient areas. Practices such as drip, sprinkler, and sensor irrigation, as well as traditional methods of mulching and pitcher irrigation, ensure efficient utilization of water and maximize crop yields. Encouraged by government initiatives, technological innovation, and global cooperation, these methods minimize water loss, enhance the efficiency of inputs, and adopt climate-resilient agriculture to provide sustained food and water security.

Introduction

Water is arguably the most important agricultural natural resource, which has a direct effect on the growth of crops, yield, and food security. With the rising population pressure, urbanization, industrialization, and effects of climate change, availability of water is coming down to critically low levels. Agriculture, which utilises more than 70% of global freshwater, now has to function with higher water-use efficiency. Flood or furrow irrigation is conventional and usually leads to a loss of a lot of water by evaporation, deep percolation, and runoff, hence decreased efficiency and greater environmental stress.

To overcome such challenges, the use of water-saving irrigation methods has emerged as a key strategy for sustainable agriculture development at Chathuranika *et.al.* 2022. Such methods seek to optimize crop productivity with minimal water use by optimizing irrigation timing, distribution, and amount. The hybridization of smart irrigation system technologies with conventional knowledge and a supportive government can significantly improve water-use efficiency, decrease monsoon rainfall dependency, and aid in long-term agricultural sustainability.

2.1 The necessity for effective irrigation

Effective irrigation is no longer a choice—it is a requirement. Agriculture continues to be the biggest user of freshwater worldwide, with withdrawals totaling over 70% of total withdrawals. Ineffective irrigation methods have resulted in severe issues like soil salinity, waterlogging, and nutrient leaching, which eventually reduce land productivity.

In addition, irregular rainfall patterns, decreasing reservoirs, and over-extraction leading to groundwater depletion are compelling farmers to opt for more robust and efficient irrigation systems. Better irrigation methods not just assist in saving

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water but also lead to increased yields, reduced input costs, healthier soils, and enhanced profitability. Water-saving technologies are especially critical in arid and drought-prone areas, where water is a production constraint for agriculture. Promoting awareness and adoption of these techniques is essential for achieving climate-smart and sustainable agriculture.

3. Types of Water-Saving Irrigation Techniques

Effective irrigation is the hallmark of new-age, sustainable agriculture. A number of water-conserving methods have been devised in order to enhance water-use efficiency and curtail wastage. These methods aim to supply water exactly where and when needed, with negligible losses from evaporation, runoff, or deep percolation. Among these, drip, sprinkler, and subsurface irrigation systems are universally embraced based on their well-established performance under various agro-climatic conditions. Fazliev *et.al.* 2019.

Source: https://www.nidwater.com

3.1 Drip Irrigation

Drip irrigation is the most effective irrigation system, in which water is applied directly at the plant root zone through a system of pipes, tubes, and emitters. This localized system of watering suppresses evaporation and runoff, saving a lot of water.

- It saves 30–70% more water compared to traditional surface irrigation techniques.
- Targeted application of water suppresses weed growth, restricts contact of water with leaves and stems, and thus reduces disease incidence.
- It is most appropriate for valuable crops like fruits, vegetables, cotton, sugarcane, and nursery plants.

3.2 Sprinkler Irrigation

Sprinkler irrigation systems deliver water under pressure through nozzles, which imitate natural rainfall.

- They are most effective on sloping land, sandy lands, and where there are issues with non-uniform water distribution.
- This method is most suitable for crops such as wheat, maize, pulses, and oilseeds.
- It greatly minimizes water loss through surface runoff and deep percolation, enhancing irrigation uniformity and water effectiveness.

3.3 Subsurface Irrigation

Subsurface irrigation involves delivering water below the soil surface directly to the root zone by buried pipelines or drip lines.

- It saves a lot of evaporation and prevents wind drift, thus it is very efficient.
- Promotes deep root growth and improves plant health.
- Suits best for greenhouses, polyhouses, and high-value commercial crops.

4.New and Smart Irrigation Technologies

The new agriculture is transforming at a fast pace with the adoption of new irrigation technologies, which not only save water but enhance productivity of crops and efficiency of inputs as well. These smart irrigation systems allow timely and accurate application of water according to crop requirements and environmental factors. Thompson *et.al.* 2009.

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4.1 Sensor-Based Irrigation Systems

Soil moisture sensors and plant indicators are used in sensor-based irrigation to measure the precise water needs of crops. Sensors are placed at different soil layers to identify moisture content and provide real-time information to control systems. Once the soil moisture drops below a certain level, the system switches on irrigation automatically. The process avoids over-irrigation, saves water, and enhances nutrient use efficiency. It also reduces water stress in crops, resulting in improved growth and yield.

4.2 IoT and Mobile-Controlled Irrigation

Internet of Things technology allows remote management of irrigation via intelligent devices. Farmers may use smartphones or tablets to control and monitor irrigation systems using sensor data and weather forecasts. IoT platforms gather data on soil moisture, crop development stages, and regional climate, allowing for better decision-making. Automation of irrigation conserves labor, minimizes water loss, and enhances working efficiency, particularly in commercial-scale agriculture.

4.3 Automated Micro-Irrigation

It brings micro-irrigation techniques such as drip and sprinkler irrigation together with automation devices including timers, solenoid valves, and programmable controllers. It makes precise delivery of water in quantities needed at the right time. Automated micro-irrigation is suitable for high-value crops in greenhouses, orchards, and polyhouses. It provides even water distribution, cuts down human labor, and supports sustainable agriculture.

5.Traditional and Indigenous Water-Saving Practices

Besides the advanced technologies, indigenous and traditional irrigation methods make an essential contribution to water conservation, particularly in water-scarce and arid environments. Such techniques, inherited from centuries of farmers' practice and experience, are eco-friendly, inexpensive, and usually very effective in conserving soil moisture and sustaining crop yields with limited water supply.

5.1 Mulching and Soil Moisture Conservation

Mulching refers to the process of putting organic material like straw, leaves, crop residues, or plastic films on top of the soil surface. Organic mulches lower evaporation, prevent weeds from germinating, and enhance the structure and fertility of the soil as they break down. Plastic mulches, in vegetable production, provide a physical cover that prevents water loss from the soil surface and ensures even soil moisture levels. These practices find special applicability in dryland farming where water shortages constrain cropping, imposing unusually high water-use efficiency and less frequent irrigation. Kulkarni *et.al*. 2011.

5.2 Alternate Wetting and Drying (AWD) in Rice

AWD is a type of irrigation in rice cultivation in which the paddy field is not kept flooded continuously but alternately dried and later irrigated. This technique can conserve 20–30% of the irrigation water without sacrificing grain yield. AWD promotes deeper root growth, enhances plant resistance, and limits the emission of methane — a potent greenhouse gas in traditional rice production. AWD is becoming increasingly popular as a climate-resilient practice for sustainable rice cultivation.

5.3 Pitcher and Pot Irrigation

Pitcher irrigation entailed planting porous clay pitchers or pots close to the roots of the plants and filling them with water. The water would slowly trickle into the soil around it, reaching the root zone of the plant directly. It is an old method that reduces water loss through evaporation and runoff. It is particularly ideal for home gardening, small farming, and water-scarce locations. Being easy to use, inexpensive, and efficient, it is still a very useful method for reducing water loss in arid regions.

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6. Government Support and Policy Initiatives

Seeing the pivotal role of effective irrigation for sustainable agriculture and water saving, the Indian government and different state agencies have initiated focused schemes and policy programs. The plans are set to encourage micro-irrigation, water harvesting, and climate-smart practices, particularly in water-scarce and agricultural states. Support also comes through international collaboration and private sector involvement through CSR.

6.1 PMKSY – Per Drop More Crop

The Government of India's prime scheme for enhancing on-farm water use efficiency is the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). Micro-irrigation like drip and sprinkler irrigation is encouraged under its component Per Drop More Crop. The scheme provides financial support up to 55% for general category farmers and up to 60–70% for SC/ST and small/marginal farmers. Special emphasis is laid upon water-intensive agriculture and dryland areas, with the goal of providing "Har Khet Ko Pani" (water to all fields).

6.2 State-Specific Schemes

Various states have introduced their own irrigation schemes to deal with regional water issues:

- Maharashtra's Jalyukt Shivar Abhiyan emphasizes desilting, farm pond development, and watershed development to render villages drought-free.
- Karnataka's Krishi Bhagya Scheme promotes rainfed agriculture with water harvesting structures such as farm ponds, and promotes the adoption of micro-irrigation to achieve maximum water productivity.

These schemes are region-specific and complement national programs.

6.3 International Partnerships and CSR Initiatives

International agencies and private organizations are increasingly contributing to improving irrigation efficiency in India:

Organizations like the World Bank, ICAR, and FAO fund pilot projects and training initiatives on smart irrigation systems.

Firms like Jain Irrigation and Netafim donate under Corporate Social Responsibility (CSR) in the form of technology, training, and drip irrigation systems to smallholders.

Such collaborations reinforce India's irrigation ecosystem through innovation, investment, and capacity-building.

7. Challenges, Success Stories, and Future Outlook

The shift towards efficient and contemporary irrigation systems holds immense promise but also challenges. While some countries and states have already realized the advantages of smart irrigation, wider application has to overcome economic, technical, as well as infrastructural bottlenecks. A harmonious mix of policy incentives, technology, and farmer capacity building is necessary for effective water management.

7.1 Challenges

In spite of the benefits of micro and smart irrigation systems, various challenges stand in their way to mass adoption:

- High Initial Expenditure: Drip and sprinkler system installation involves enormous initial costs, which most small and marginal farmers are unable to bear.
- Technical Inadequacy and Unawareness: Most farmers lack knowledge about the advantages of these systems or are poorly trained to work and maintain them efficiently.

- Maintenance Problems and Post-Sales Service: Clogging, deterioration, and irregular maintenance result in system inefficiencies and farmer discontent.
- Limited Coverage in Remote and Tribal Regions: Gaps in infrastructure and logistical issues make it difficult for these technologies to extend to remote areas, where they are most required.

7.2 Success Stories

A number of national and global examples illustrate how successful planning and implementation can result in better irrigation practices:

- Israel: Worldwide known for innovating drip irrigation and water recycling, with high yields at low water usage.
- •\tAndhra Pradesh: Horticultural belt farmers have embraced automated drip systems with mobile applications, with considerable enhanced productivity and resource utilization.
- Punjab and Haryana: Sprinkler irrigation of wheat and mustard is encouraged in these states to offset depleting groundwater levels, with noticeable improvement in water-use efficiency.

7.3 Future Outlook and Recommendations

To overcome challenges and guarantee sustainable irrigation, the following are imperative steps:

Enhance Integrated Irrigation Management: Integrate conventional practices such as mulching or pot irrigation with intelligent technologies to ensure site-specific water management.

Scale Up Digital Advisory Platforms: Increase mobile and IoT-enabled solutions for real-time irrigation scheduling and decision-making support.

Training and Capacity Building: Organize continuous training programs for farmers and field officers to develop technical competency and awareness.

Public-Private Partnerships: Support partnerships between the government, industry, and NGOs to subsidize expenses and expand service networks.

Propose Climate-Resilient Crops: Promote growing crops with less water demand and greater drought resistance to be in line with evolving climate realities.

8. Conclusion

Water-saving irrigation technologies are crucial to developing sustainable and climate-resilient agriculture. Combining traditional practices such as mulching and pitcher irrigation with recent advances such as sensor-based systems, IoT, and automated micro-irrigation ensures effective use of water and increased crop yields. Government schemes, state initiatives, and global partnerships further encourage widespread implementation. Nevertheless, challenges such as high upfront costs, limited awareness, and insufficient access in rural regions are still important to address. By maintaining policy support, capacity building, and public-private partnerships, India can effectively save water and ensure the future of its agriculture.

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Nutritional Practices and Feeding Resources for Poultry: Strategies for Optimal Production

Farrukh Shaz, Krishna Kumar and Uzma Manzoor
School of Agriculture, Galgotias University, Greater Noida-201310 (U.P.) India

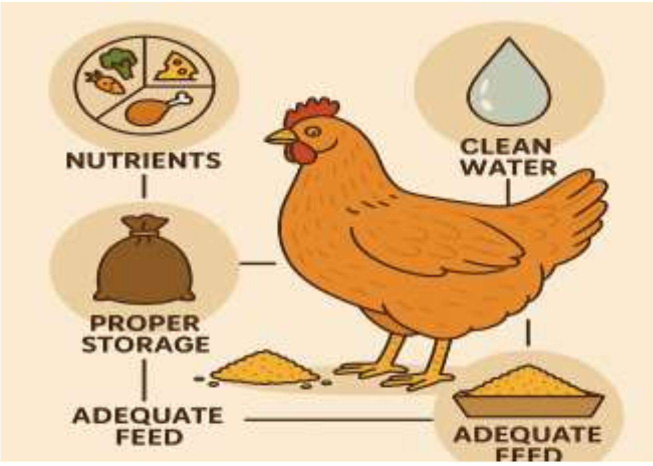
Introduction

As a significant source of animal protein, poultry farming is essential to supplying the world's demand for meat and eggs. Effective feeding management, which has a direct impact on growth, health, productivity, and overall farm profitability, is crucial to the success of poultry production. Each stage of the life cycle-starter, grower, and layer or broiler phases-has distinct dietary needs for poultry species, such as chickens, ducks, quails, and turkeys. Thus, choosing the right feed materials and being aware of their feeding patterns are essential to getting the best results. Feeding poultry entails giving them well-balanced meals that include vital nutrients such water, vitamins, minerals, proteins, carbs, and fats. Cereals like wheat and maize, oilseed cakes, fish meal, and vitamin-mineral supplements are examples of common feed ingredients.

Furthermore, feeding techniques such phase feeding, restricted feeding, and ad libitum feeding are used according to the type of bird and the production objective. Furthermore, understanding the natural feeding habits of birds-such as pecking, scratching, and foraging-assists in creating more efficient feeding systems that minimize waste. In order to help farmers and poultry managers make better decisions for the health, productivity, and sustainable management of their flocks, this guide attempts to shed light on the feeding habits of poultry and emphasize appropriate feed ingredients. The secret to healthy and prosperous poultry farming is efficient feeding management. Poultry, including chickens, ducks, and turkeys, require a balanced diet to increase egg production and general health. Farmers can save expenses by knowing their feeding patterns and nutritional requirements.

Principle of Feeding Poultry

1. Birds have no lips or teeth so they cannot chew their feed hence the ration is chiefly consisting of concentrates.
2. They have simple stomach of their nutrition requirement more precise and specific.
3. They have higher rate of metabolism.
4. Birds are fed in group.
5. Feed must contain all the nutrients in balance form.
6. Feeds must be appetizing and free form.
7. Always provide fresh clean cool water all the time.

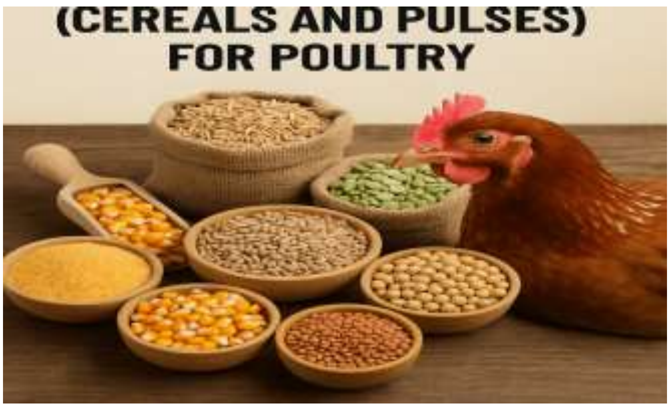


Cereal and Pulses grains and their byproducts

- ❖ Dry matter of cereal grains should be 90%.
- ❖ Protein- crude protein content of grains ranges from 8-12% cereal. proteins are

deficient in certain indispensable amino acids particularly lysine and methionine.

- ❖ Lipids- wheat Barley rye rice contain 1 - 3% lipids. Lipid content is highest in oats 4-6% and lowest in wheat 1-2% cereal oils are unsaturated fatty acids main acids being Lenoleic and oleic.
- ❖ Crude fibre- Highest amount of crude fibre is present in oats and rise which contain a husk or Hull. Crude fibre is lowest in naked grains wheat and maize.
- ❖ Minerals- All grains are deficient in Ca (0.1% or less) and p (0.3-0.5) but part of this is present as phytic acid which is concentrated in the all aleurone layer cereal phytates bind with Ca and probably Mg thus preventing their absorption.
- ❖ Vitamins- cereal grains are deficient in vitamin A with exception of yellow maize having good amount of vitamin A.
- ❖ Starch- Cereal starch occurs in the endosperm of grain in the form of granules cereal starch consists of 25% amylose and 75% amylopectine.
- ❖ Plant origin oil cakes- Cakes have higher protein and fat content.
- ❖ Groundnut cake- Groundnut seeds contain 35-60% oil and 25-30% crude protein
- ❖ Soybean meal- (SBM) normally solvent extracted oil is 1% most of the SBM.
- ❖ Mustard oil cake- Oil content is high 14.1% crude protein content is 35%ca and p content are very higher.

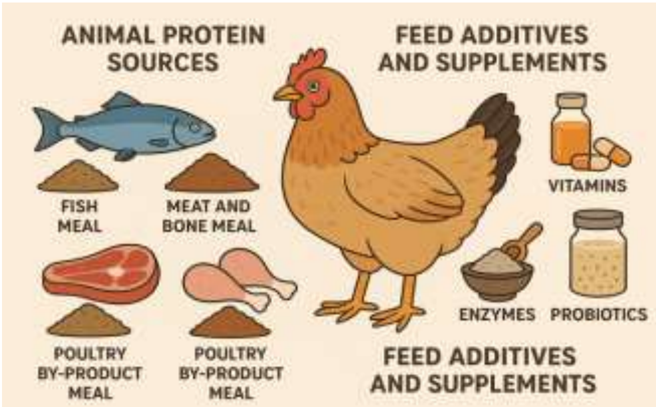


Animal origin protein sources

- ❖ Fish meal- richest source of vitaminB12
- ❖ Meat meal- Good source of vit B complex
- ❖ Blood meal- The product is obtained by dry the blood of slaughtered warm-blooded animal.

Feed supplement and additives in poultry

- ❖ Supplement are nutritional substances which are added in the feeds to supply those nutrients which are deficient in ration.
- ❖ Additives are non-nutritive substances added in the feed to improve intake digestion absorption and utilization of nutrients for better growth and production performance of birds.



Some important feed additives

1. Antibiotics
2. Probiotic
3. Prebiotic
4. Acidifier
5. Enzyme

Conclusion: -

Proper feeding and water management ensure healthy, productive poultry. By balancing nutrients, using appropriate feed types, and employing efficient feeding systems, farmers can boost productivity and lower costs, supporting sustainable poultry farming.

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Soil-Legume Interactions in Agroecosystems

[1]Hari Shankar Singh*, [2]Dr. Anil Kumar, [3]Sugandha Chauhan, [4]Shivali Rana, [5]Manjul Jain

[1]Ph.D. Scholar, Deptt. Soil Science and Agriculture Chemistry, Chandra Shekhar Azad University of Agriculture and Technology Kanpur- 208002

[2,5]Assistant Professor, Department of Agronomy, School of Agriculture, Eklavya University Damoh, Madhya Pradesh-470661

[3]Ph.D. Scholar, Deptt. of Soil Science, CSKHPKV PALAMPUR H.P.-176062

[4]Ph.D. Scholar Deptt. of Agronomy, CSKHPKV PALAMPUR H.P. -176062

Introduction

Legumes are crucial to sustainable farming due to their peculiar capacity to establish symbiotic associations with soil microbes, particularly rhizobia, which enable biological nitrogen fixation (BNF). Naturally, through this process, legumes transform atmospheric nitrogen (N_2) into forms that can be used by plants like ammonium (NH_4^+), thus enhancing soil nitrogen contents. This greatly lowers the reliance on synthetic nitrogenous fertilizers, which tend to be expensive and environmentally unsound.

Soil-legume association extends beyond nitrogen fixation. Legume roots exude substances that induce desirable microbial activity in soil, advancing overall soil biological health. Root architecture of legumes promotes soil aggregation, porosity, and water penetration. Additionally, adding residues from legumes increases organic matter and enhances soil structure, fertility, and capacity to sequester carbon.These interactions are at the core of agroecological intensification, which aims to enhance productivity while preserving natural resources. Integrating legumes in cropping systems—either as intercrops, cover crops, or in rotation—increases nutrient cycling, improves biodiversity, and helps foster ecosystem services including pest control and soil conservation. Aslam *et.al.* 2025.

Knowledge of soil-legume interactions optimizes legume performance and soil health benefits. This involves awareness of the role of soil pH, nutrient availability (especially phosphorus and molybdenum), and proper Rhizobium inoculation to facilitate efficient nodulation and nitrogen fixation.In times of climate change, soil loss, and increased input prices, encouraging legume-based systems presents a low-input, sustainable alternative. Therefore, improving soil-legume interactions is an effective approach to constructing resilient, productive, and environmentally friendly agroecosystems.

2. Benefits of Soil-Legume Interactions

2.1 Biological Nitrogen Fixation (BNF)

Legumes have the exclusive capacity to nitrogen-fix atmospheric nitrogen by means of symbiotic relationship with particular Rhizobium bacteria in the soil. These bacteria infect the root nodules and transform atmospheric nitrogen (N_2) to ammonium (NH_4^+), a form of nitrogen accessible to the plant. This process not only satisfies the nitrogen needs of the legume itself but also adds nitrogen to the soil surrounding it, which is available to follow-up or companion crops. Through natural provision of nitrogen, legumes lower the demand for expensive and ecologically destructive synthetic nitrogen fertilizers, thus encouraging low-input sustainable agriculture. In intercropping or crop rotation cropping systems, this symbiotic benefit accrues to non-legume crops like cereals, increasing overall productivity and resource-use efficiency.

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Source: https://www.frontiersin.org

Source: https://www.nature.com

2.2 Organic Matter and Soil Structure

Legume root systems are important contributors to the improvement of soil structure. The extensive root systems encourage soil aggregation, improving the physical stability of soil. Legumes also increase the porosity and aeration of soil, facilitating enhanced root penetration and microbially mediated processes. Root decomposition of legumes and return of crop residues to the soil add considerable organic matter, which is crucial to ensuring soil fertility, water-holding capacity, and microbial activity. This addition of organic matter is particularly critical in degraded or deficient soils to repair and rejuvenate soil quality over a period.

2.3 Weed and Pest Suppression

Legumes also have an indirect but significant impact on weed and pest management. Certain legume species release allelopathic chemicals—natural biochemicals that inhibit the germination or growth of weeds. By disrupting pest cycles with rotation and diversification of the cropping system, legumes restrict pest accumulation. Additionally, the environment provided by legume canopies and flowers allows beneficial predators and pollinators to be present, making a contribution towards natural regulation of pests. These characteristics make legumes valuable components of integrated pest and weed management programs.

3. Soil Factors Influencing Legume Performance

Legume growth and biological nitrogen fixation (BNF) efficiency rely heavily on some key soil physical, chemical, and biological characteristics. All these factors affect nodulation, microbial populations, nutrient availability, and plant health.

3.1 Soil pH

Soil pH is an important aspect of legume-Rhizobium symbiosis. Most legume crops perform best in soils with a pH between 6.0 and 7.5. In acidic soils ($pH < 6.0$), Rhizobium bacterial survival, colonisation, and growth are weakened, resulting in poor nodulation and reduced nitrogen fixation. Soil acidity can be counteracted using agricultural lime application. Liming increases pH to optimum levels, hence microbial growth and root growth and nodulation.

3.2 Soil Texture and Drainage

Legumes develop optimally in well-drained loamy soils that facilitate sufficient air and water movement. Waterlogged and poorly drained soils restrict root respiration as well as microbial activity, which can repress nodulation and induce root rot. In contrast, sandy soils can be aerated but tend to be low in fertility and water retention, which can restrict nutrient uptake and plant growth. Therefore, ideal soil texture as well as management of drainage is crucial for the health of legumes.

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3.3 Soil Nutrient Status

There should be essential nutrients in sufficient amounts for efficient BNF. Phosphorus (P) plays a vital role in energy transfer and nodule formation. Molybdenum (Mo), although needed in small quantities, is an integral part of the nitrogenase enzyme that catalyzes the fixation of nitrogen. Other essential nutrients such as iron, sulfur, and calcium contribute to the development of nodules and microbial activity. Proper fertilization ensures proper supply of nutrients to legumes as well as their symbiotic partners.

3.4 Soil Microbial Communities

Presence of functional indigenous Rhizobium populations in the soil significantly impacts legume nodulation. Nevertheless, in most soils, indigenous strains could be missing or nonfunctional. In such situations, seed inoculation with compatible Rhizobium strains provides efficient colonization, successful nodulation, and improved nitrogen fixation.

4. Enhancing Soil-Legume Interactions

For the optimal utilization of legumes in agroecosystems, certain management practices are needed to be implemented for augmenting their interaction with the soil constituents. These management practices facilitate efficient biological nitrogen fixation, improved soil quality, and long-term crop production.

4.1 Rhizobium Inoculation

Successful nitrogen fixation relies on a symbiotic compatibility between the legume plant and the respective Rhizobium species. Because native Rhizobium populations can be lacking or ineffective in certain soils, seed inoculation with legume-specific strains, e.g., Bradyrhizobium japonicum for soybean, is necessary. Inoculants must be fresh and viable, and applied with adequate seed-coating technology to maximize contact and survival. For better performance, concurrent application of molybdenum and phosphorus is advisable, as these are essential for nodule function and energy metabolism in nitrogen fixation.

4.2 Integrated Nutrient Management (INM)

Legumes are favored with a balanced input of nutrients, and INM makes both organic and inorganic inputs work together to ensure soil fertility sustainably. Organic inputs such as farmyard manure and compost enhance the soil structure and microbial activity, and inorganic fertilizers provide the specific nutrient needs. Excessive application of nitrogen fertilization must be circumvented, though, since it can inhibit nodulation by minimizing the dependence of the plant on BNF. In its place, sufficient amounts of phosphorus, potassium, sulfur, and micronutrients like zinc and molybdenum must be used to promote maximum legume growth and nodule functionality. Everwand *et.al.* 2017.

4.3 Crop Rotation and Intercropping

Legumes have a useful place in diversified cropping systems. Alternating legumes with nitrogen-fixing crops such as cereals enhances nitrogen use efficiency and interrupts cycles of pests and diseases. In intercropping systems, legumes intercropped with cereals promote overall productivity, increase soil cover, and minimize erosion. Legumes may also be employed as cover crops or fallows and offer permanent soil cover, minimize weed pressure, and add organic residues that improve long-term soil health and fertility.

4.4 Soil Conservation Practices

Implementation of soil conservation methods like contour farming, minimum tillage, and residue maintenance still further facilitates soil-legume interaction. These methods shield the soil from erosion, enhance water infiltration, and provide a suitable condition for microbial life. When cover crops are planted with legumes, they hold the soil in place, minimize surface runoff, and enhance moisture

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storage, and are thus useful for developing climate-resilient agriculture systems.

5. Impact on Agroecosystem Services

Soil-legume relationships go far beyond crop nutrition—they are directly involved in supporting a diversity of ecosystem services sustaining agricultural productivity, biodiversity, and environmental resilience. Their integration into agricultural systems results in quantifiable gains on ecological, economic, and social fronts. Gogoi, *et.al.* 2018.

5.1 Soil Fertility and Productivity

One of the most important benefits of legumes is the improvement of soil fertility due to biological nitrogen fixation and organic matter addition. Symbiotic action of Rhizobium bacteria raises the soil nitrogen levels, which are available for legumes and other crops. The degradation of residues also adds to soil organic carbon levels, enhancing soil structure, and water holding capacity. Legume production in rainfed and degraded areas favors sequential enhancement of long-term fertility, which allows poor farmers to restore productivity in a sustainable manner.

5.2 Biodiversity

Legume-based systems enhance below-ground and above-ground biodiversity. Root exudates of legume roots in the rhizosphere induce the activity of beneficial soil fauna, fungi, and microbes, creating a dynamic and healthy soil ecosystem. Above ground, the flowering habit of legumes supports pollinators and natural enemies of pest species, increasing agroecological diversity. This diversity enhances system stability and resilience to biotic and abiotic stress.

5.3 Climate Change Mitigation

The inclusion of legumes in agroecosystems supports climate-smart agriculture. By replacing or minimizing synthetic nitrogen fertilizers, legumes reduce greenhouse gas (GHG) emissions, primarily nitrous oxide (N_2O), a powerful GHG. Legumes also enhance carbon sequestration by their roots and crop residue, fixating atmospheric carbon in soils and countering global warming.

5.4 Economic and Livelihood Benefits

From the socio-economic point of view, legumes have many benefits. Their nitrogen fixation results in reduced input costs for smallholders. The marketing of legume grains and biomass generates increased income, while their feed value to livestock increases the value of mixed farming enterprises. Legumes are protein-rich and enhance household nutrition and food security, thus making them essential to sustainable rural livelihood.

6. Constraints and Management Strategies

Constraint	Management Strategy
Poor nodulation	Inoculation with effective Rhizobium strains
Acidic soils	Liming to increase pH to 6.0–7.0
Micronutrient deficiency (Mo, Zn)	Apply appropriate foliar or soil micronutrients
Drought stress	Choose drought-tolerant legume varieties
Competition in intercrops	Maintain optimal plant spacing and sowing time

7. Case Studies and Successful Models

7.1 Pulse Villages in India

The Government of India and various research institutions have promoted the concept of "Pulse Villages" to boost pulse production in targeted regions. These areas focus on the systematic promotion of legumes such as chickpea, pigeon pea, lentil, and mung bean. Through the adoption of improved seed varieties, biofertilizer applications, and refined agronomic practices, farmers have

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achieved significantly higher yields and incomes. The integration of legumes into existing cropping systems has also led to noticeable improvements in soil fertility, especially in rainfed and nutrient-deficient areas. These villages serve as models for sustainable agriculture, demonstrating how legume-based systems can restore soil health while enhancing rural livelihoods. Nabel *et.al.* 2018.

7.2 Conservation Agriculture with Legumes

In several parts of India and sub-Saharan Africa, conservation agriculture practices incorporating legumes such as cowpea and pigeon pea into no-till and residue-retention systems have shown promising results. These legumes not only provide ground cover, reducing erosion and suppressing weeds, but also improve soil organic matter, microbial activity, and moisture retention. Such systems promote yield stability, even under variable climate conditions. This approach highlights the synergy between legumes and conservation agriculture in achieving resource-use efficiency, climate resilience, and long-term sustainability in agroecosystems.

8. Conclusion

Soil-legume interactions are central to sustainable and climate-smart agriculture. By leveraging the natural ability of legumes to fix nitrogen, improve soil health, and contribute to ecological balance, agroecosystems can become more productive, resilient, and environmentally friendly. For farmers, researchers, and policy-makers, promoting legumes in cropping systems-backed by sound soil management, inoculation strategies, and appropriate nutrient management-is a path toward sustainable agricultural intensification.

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Nano-enabled RNAi: A Next-Generation Strategy for Sustainable Agriculture

Poonam Kumari, Pooja, Laxmi
Department of Molecular Biology and Biotechnology, Maharana Pratap University of Agriculture and Technology, Udaipur-313001 (Raj.), India

RNA interference (RNAi)-based strategies are revolutionizing modern agriculture by offering a targeted, eco-friendly, and highly effective means of pest control, gene regulation, and stress mitigation. When combined with nanoformulations, the delivery of RNA molecules particularly double-stranded RNA (dsRNA) and small interfering RNA (siRNA) can be made significantly more stable, efficient, and scalable for field use. This article explores the synthesis and mechanisms of RNA-based nanoformulations, discusses their applications in pest and disease control, evaluates the role of various nanocarriers in enhancing uptake and gene silencing, and outlines the challenges and future perspectives of this next-generation biotechnology.

Introduction

Global agriculture is under immense pressure to meet the rising food demands of a growing population while facing challenges such as climate change, limited natural resources, and increasing resistance to conventional agrochemicals (Zhao et al., 2024; Ranjan et al., 2025). Traditional pesticides often lack specificity, harm non-target organisms, and contribute to environmental degradation (Li & Gao, 2023; Mujtaba et al., 2021). Among emerging technologies, RNA interference (RNAi) has drawn significant attention for its precision and versatility. RNAi offers a precise, eco-friendly solution by silencing specific genes in pests or plants, making it a promising alternative to chemical-based crop protection (Singh et al., 2021). However, the practical application of RNAi in the field is limited by the instability of RNA molecules, which degrade rapidly under environmental conditions and face delivery barriers in plant or pest systems (Wang et al., 2023; Qiao et al., 2024). To address these limitations, nanotechnology-based RNA delivery systems have emerged as a transformative approach. Nanoformulations protect RNA molecules from degradation, enhance uptake, and enable targeted delivery, making RNAi more viable for large-scale agricultural use (Patel et al., 2024; da Silva et al., 2024). Despite the proven efficacy of RNAi in lab settings, its limited stability and delivery efficiency in field environments create a significant implementation gap. This article focuses on how nanotechnology bridges this gap.

Mechanism of RNAi in Plants and Pests

RNAi works by introducing double-stranded RNA (dsRNA) into plant cells or pest bodies. The dsRNA is processed into small interfering RNA (siRNA) by Dicer enzymes (Figure 1). These siRNAs are incorporated into the RNA-induced silencing complex (RISC), which targets and cleaves complementary messenger RNA (mRNA), thereby silencing the gene of interest. In pest management, RNAi can target essential genes in insects, fungi, or nematodes disrupting development, metabolism, or reproduction. In plants, RNAi can suppress genes related to stress susceptibility, enhancing resilience.

Integration of Nanotechnology for better RNAi application

Optimizing the size and shape of nanocarriers is crucial for efficient RNA delivery in plants. Since the cuticle pore size is approximately 2 nm and cell wall pores are typically less than 20 nm, nanocarriers must be below this threshold to ensure successful uptake and transport. Nanoparticles smaller than 20 nm can

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more easily penetrate plant tissues and deliver RNA molecules effectively. Additionally, the shape of the nanocarrier influences uptake; in the case of non-spherical nanoparticles such as single-walled carbon nanotubes (SWNTs), the diameter plays a more critical role than length in determining their ability to pass through cellular barriers.

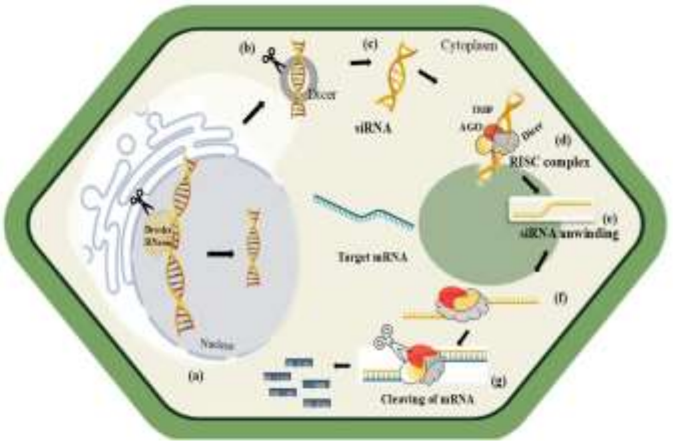

Figure 1: Schematic representation of RNAi A of (a) long dsDNA by Drosha RNase, and export to the cytoplasm, (b) Dicer binding leads to the fragmentation of dsRNA into (c) siRNAs, (d) recruitment of siRNA by the RISC-protein complex, (e) unwinding of siRNA, (f) binding of siRNA to target mRNA, (g) cleaving of mRNA and leads to the formation of disrupted protein. (adapted from Mathur et al., 2025.)

Types of Nanocarriers Used for RNA Delivery

1. Lipid-Based Nanocarriers: Liposomes and solid-lipid nanoparticles (SLNs) encapsulate RNA molecules within lipid bilayers, protecting them from enzymatic degradation and facilitating membrane fusion during delivery, with added advantages of being biocompatible, non-toxic, and easily customizable for foliar or root applications.

2. Polymeric Nanocarriers: Chitosan, polyethyleneimine (PEI), and dendrimers are commonly used to create cationic carriers that electrostatically bind negatively charged RNA, offering advantages such as stability under field conditions, low cost, and easy biodegradability.

3. Carbon-Based Nanocarriers: Carbon nanotubes (CNTs), graphene oxide, and carbon dots have shown remarkable RNA loading and translocation abilities. A 2024 Nanoscale article discussed the use of single-walled CNTs for RNA delivery into plant chloroplasts with >80% uptake efficiency (RSC Nanoscale), offering advantages high surface area, effective transmembrane delivery, tunable surface chemistry.

4. Inorganic Nanocarriers: Layered double hydroxides (LDHs), silica nanoparticles, and gold NPs offer structural rigidity and can be used for controlled-release systems. A recent MDPI review (2023) highlighted the successful delivery of RNA pesticides using silica nanoparticles, reducing fungal infection in tomato crops by 70% (MDPI Nanomaterials).

5. Virus-like nanoparticles (VLPs): Mimic virus structure (2-200 nm) but are genome-free and safe. Offer targeted RNA delivery using plant viral capsids and surface ligands. Allow precise modification and enhanced gene silencing through self-assembly with siRNA and use of cell-penetrating peptides.

6. Nanogels: Soft, hydrogel-based nanoparticles (40-200 nm) designed for RNA protection and delivery. Provide uniform size, resistance to enzymatic degradation, and effective gene silencing. Variants like PDA-coated and bis-intercalator-based nanogels also support therapeutic RNA delivery and stress-response modulation.

Applications in Agriculture

1. **Insect Pest Control**: RNAi-nanoformulations targeting vital insect genes (e.g., *Helicoverpa armigera*) achieve up to 90% pest mortality with minimal dosage and high specificity, reducing harm to beneficial organisms.
2. **Viral Disease Management**: Liposome-encapsulated dsRNA targeting viral replication genes (e.g., *Tomato Yellow Leaf*

Curl Virus) effectively delays symptoms and reduces viral load by 80%, preventing systemic infection.

3. **Fungal & Bacterial Resistance:** dsRNA-loaded cellulose nanocarriers inhibit fungal pathogens like *Rhizoctonia solani*, providing extended RNA protection and significantly lowering disease incidence in crops like rice.
4. **Abiotic Stress Tolerance:** Chitosan-RNA complexes modulate stress-responsive genes (e.g., ABA-pathways), enhancing drought resistance in maize and boosting crop yield by 15%.

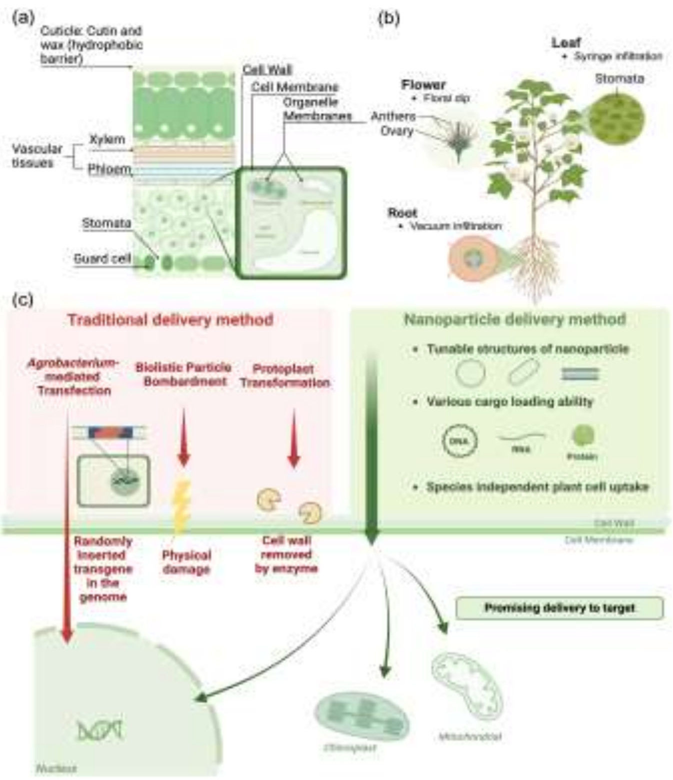

Figure 2: Challenges and possible delivery region for nanoparticle transport into plant cells. (a) Existing physical barriers which might affect nanoparticle transport from the leaf epidermis into the inner mesophyll. (b) Possible tissue regions and related possible delivery methods for biomolecule delivery *via* nanoparticles. (Floral dip can be used for flower delivery. Syringe infiltration can be applied to leaves. Vacuum infiltration can be used for root delivery.) (c) The comparison between features of traditional delivery systems and nanoparticle delivery methods. (adapted from Zhao et al., 2024)

Nano driven RNAi: Pros and cons

Feature	**Traditional Pesticides**	**RNA-Nanoformulations**
Target Specificity	Broad-spectrum, non-specific	Gene-specific, highly targeted
Environmental Safety	Risk of residues, runoff	Biodegradable, minimal toxicity
Resistance Development	High (due to overuse)	Low (gene-specific modes)
Field Stability	Degrades quickly	Enhanced via nanocarriers
Dose Efficiency	High doses required	Low doses due to high efficacy

Challenges and Future Directions

Despite their potential, RNA-based nanoformulations face challenges such as regulatory uncertainty, variability in field efficacy due to environmental factors, high costs of certain nanocarriers, and limited understanding of plant uptake mechanisms. To overcome these, translational nanomedicine approaches are being adapted for agriculture, with startups developing biodegradable, plant-specific RNA carriers. Green synthesis using natural polymers is gaining popularity to minimize ecological impact. Additionally, integrating RNA nanoformulations with AI-powered precision tools like nanosensors and smart sprayers could enhance targeted delivery, reduce waste, and improve field-level efficiency.

Conclusion

RNA-based nanoformulations represent a paradigm shift in agricultural science uniting the specificity of molecular biology with the delivery precision of nanotechnology. As a next-generation strategy, they offer tailored pest control, enhanced stress tolerance, and improved sustainability with reduced environmental footprints. Continued research, policy support, and interdisciplinary collaboration will be key to unlocking their full potential in global agriculture.

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Sunflower Power: The Flower That Inspires, Feeds, and Heals

Mr. Saurabh Godara
Department of Genetics and Plant Breeding, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore

1.Introduction

The sunflower (*Helianthus annuus*) is far more than a vibrant bloom; it is a botanical marvel celebrated for its striking beauty, nutritional richness, health benefits, and environmental contributions. From ancient civilizations to modern-day farms, kitchens, and art studios, sunflowers have woven themselves into the fabric of human life. This article traces the sunflower's journey from its symbolic roots to its multifaceted roles today, revealing how it inspires, nourishes, and heals communities worldwide.

2 The Inspiring Beauty of Sunflowers

2.1 Iconic Appearance and Symbolism

Sunflowers are instantly recognizable by their large, radiant yellow petals, dark central discs, and tall, sturdy stems that can tower up to 12 feet or more. Their unique trait of heliotropism—tracking the sun across the sky—captivates observers and makes them a powerful symbol of positivity and resilience. This sun-chasing behavior, most prominent in young sunflowers, reflects an innate adaptability that resonates deeply across cultures.

• **Symbolism**:

– Across cultures, sunflowers embody happiness, hope, and loyalty, often associated with warmth and vitality.

– The Aztecs and Incas revered them as sacred emblems of the sun god, incorporating them into rituals and art.

– In modern times, sunflowers symbolize eco-friendliness and anti-nuclear activists, notably used in campaigns following nuclear disasters like Fukushima.

– In Ukraine, the sunflower is a national symbol, representing peace and resilience amid challenging times.

Sunflower heads demonstrate nature's mathematical genius with perfect spirals of seeds.

2.2 Sunflowers in Art and Culture

Immortalized in Vincent van Gogh's iconic Sunflowers series, these blooms have inspired artists, poets, and designers for centuries. Their bold colors and striking forms appear in paintings, literature, and even modern media, from films to social media aesthetics. Sunflowers also feature prominently in cultural events, such as:

• **Festivals and Community Plantings:** Annual sunflower festivals in places like Kansas, USA, and Tuscany, Italy, draw crowds to marvel at sprawling fields.

• **Fashion and Decor:** Sunflower motifs adorn clothing, home goods, and jewelry, symbolizing optimism and vibrancy.

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• **Literature and Poetry**: Poets like William Blake and Mary Oliver have drawn on sunflowers to evoke themes of joy and connection to nature.

3 Feeding the World

3.1 Sunflower Seeds and Oil: Nutritional Superstars Sunflower seeds, enjoyed as snacks, garnishes, or ingredients in baked goods, boast a robust nutritional profile that supports a balanced diet:

• **High in Healthy Fats:** Rich in unsaturated fats, particularly linoleic acid, which promotes heart health.

• **Protein and Fiber:** A valuable source of plant-based protein and dietary fiber, aiding digestion and satiety.

• **Packed with Vitamins and Minerals**: Notably high in vitamin E, B vitamins, magnesium, and selenium, which support immune function and energy production.

Sunflower oil, extracted from seeds, is prized for its mild flavor and high smoke point, making it ideal for frying, baking, and sautéing. Its versatility has made it a staple in cuisines from Europe to Asia. Additionally, cold-pressed sunflower oil retains more nutrients, offering a healthier option for raw consumption.

Table 1: Nutritional Values of Sunflower Seeds (per 100g)

Nutrient	Amount
Calories	584 kcal
Protein	20.8 g
Fat	51.5 g
Carbohydrates	20 g
Fiber	8.6 g
Vitamin E	35.17 mg
Magnesium	325 mg
Selenium	53 µg

3.2 Agriculture and Sustainability

Sunflowers are a cornerstone of sustainable agriculture, offering benefits to farmers and ecosystems alike:

• **Pollinator Support**: Their bright blooms attract bees, butterflies, and other pollinators, boosting biodiversity and aiding crop pollination.

Sunflower oil and seeds offer numerous health-

promoting nutrients.

• **Adaptability**: Sunflowers thrive in diverse climates, from temperate regions to semi-arid zones, with relatively low water and fertilizer needs.

• **Soil Health:** Their deep roots improve soil structure, prevent erosion, and enhance nutrient cycling in crop rotation systems.

• **Cover Crop Benefits:** Sunflowers are often planted as cover crops to suppress weeds and prepare fields for subsequent planting.

In regions like the Great Plains of North America and the Black Sea region, sunflowers are a major agricultural crop, supporting local economies while

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promoting environmentally friendly farming practices.

4 Healing Properties Sunflower seeds and oil have been used medicinally for centuries, with modern science validating many traditional applications:

- **Heart Health:** The high vitamin E and unsaturated fat content in sunflower oil may lower LDL cholesterol and support cardiovascular health, reducing the risk of heart disease.
- **Skin and Wound Healing**: Sunflower oil's emollient and antioxidant properties make it a popular ingredient in natural skincare, promoting hydration and aiding wound repair.
- **Anti-inflammatory Effects:** Emerging research suggests sunflower compounds, such as phenolic acids, may reduce inflammation and bolster immune function.
- **Mental Health Benefits:** The B vitamins in sunflower seeds, particularly folate, support neurological health and may help alleviate symptoms of stress and anxiety. Traditional Remedies: Native American tribes used sunflower preparations to treat snakebites, wounds, and respiratory ailments. For example, crushed sunflower leaves were applied as poultices, while seed infusions were used to soothe coughs and fevers.

5 Eco-Friendly and Sustainable

5.1 Sunflowers as Nature's Clean-Up Crew

Sunflowers excel in phyto remediation, the process of using plants to absorb heavy metals and toxins from contaminated soils. After the Chernobyl and Fukushima nuclear disasters, sunflowers were planted to extract radioactive elements like cesium and strontium from the soil, demonstrating their environmental potential.

- **Climate Resilience:** Sunflowers adapt to marginal soils and tolerate drought, making them a valuable crop in regions facing climate change challenges.
- **Carbon Sequestration**: Their rapid growth and large biomass capture significant amounts of carbon dioxide, contributing to climate change mitigation.
- **Biofuel Potential:** Sunflower seeds can be processed into biodiesel, offering a renewable energy source with lower emissions than fossil fuels

Their environmental versatility makes sunflowers a model for sustainable land management, from rural farms to urban restoration projects.

6 Sunflowers in Everyday Life

6.1 Growing Your Sunflowers Growing sunflowers is accessible to gardeners of all skill levels:

- **Planting**: Sow seeds after the last frost in well-drained, sunny soil, spacing them 12–18 inches apart to accommodate their growth.
- **Care**: Provide regular watering, especially during germination, and stake tall varieties to prevent toppling in windy conditions.
- **Harvesting:** Collect dried seed heads for snacks, bird food, or replanting. Cut heads when the back turns brown and cover with a cloth to protect from birds.

Homegrown sunflowers not only beautify gardens but also provide a rewarding harvest for personal use or sharing with wildlife.

6.2 Creative Uses: Sunflowers offer a wealth of creative applications:

- **Culinary**: Incorporate seeds into granola, salads, trail mix, or grind roasted seeds into a coffee substitute. Sunflower seed butter is a nutritious alternative to peanut butter.
- **Crafts:** Created dried arrangements, wreaths, or botanical art using sunflower heads and petals.
- **Wellbeing**: Sunflower oil is a key ingredient in massage oils, soaps, and moisturizers, valued for its skin-nourishing properties.

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• **Animal Feed**: Sunflower seeds are a favourite for birds and small animals, making them a staple in backyard feeders.

6.3 Community and Urban Beautification Cities worldwide plant sunflowers to enhance public spaces, foster community engagement, and support urban pollinators. Urban gardens and roadside plantings featuring sunflowers create vibrant, welcoming environments while providing ecological benefits. Community initiatives, such as sunflower-growing competitions, encourage local participation and environmental awareness.

7 Fun Facts and Festivals

• The tallest recorded sunflower, grown in Germany in 2014, reached over 30 feet, earning a Guinness World Record.

• Sunflower varieties include striped, red, dwarf, and giant types, offering diversity for gardeners and farmers.

• Sunflower festivals in Kansas (USA), Tuscany (Italy), and Hokkaido (Japan) attract visitors to vibrant fields, often paired with local crafts, music, and food.

• Sunflowerscanproduceupto2,000seedsperhead, making them a prolific source of food and planting material.

8 Conclusion

From their sun-chasing blooms to their applications in nutrition, health, and environmental stewardship, sunflowers stand tall as symbols of optimism, nourishment, and healing. Whether admired in art, harvested for food, planted to restore landscapes, or celebrated in festivals, the sunflower's enduring power continues to inspire and sustain communities worldwide. By embracing sunflowers in our gardens, kitchens, and cultures, we tap into their remarkable ability to uplift and unite.

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Speed Breeding in Vegetables: A New Horizon in Crop Improvement

Udham Singh, Alka Verma
Department of Vegetable Science,
G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand

Speed breeding is an innovative approach that accelerates crop improvement by significantly reducing generation time, allowing 4-6 generations per year compared to 1-2 in conventional methods. It involves extending light exposure and early seed harvest in controlled environments, such as glasshouses. This technique is especially valuable for vegetable crops, traditionally slow to breed. Speed breeding can be adapted to local resources and integrated with modern tools like genome editing and marker-assisted selection. Overall, speed breeding offers a time- and resource-efficient strategy to meet the growing demand for improved, climate-resilient crop varieties.

Introduction

Speed breeding is a technique used to accelerate plant growth and reproduction cycles, enabling multiple generations in a year. In vegetable crops, this method involves optimizing environmental conditions such as extended light hours, controlled temperature, and humidity in growth chambers or greenhouses. These conditions promote faster photosynthesis and early flowering, allowing plants to mature and produce seeds quickly. Traditional breeding cycles in vegetables may take several months, but speed breeding can reduce this to just two to three months per generation. This rapid cycling helps breeders develop improved varieties with desirable traits like disease resistance, better yield, and climate adaptability much faster. The technique is especially useful for crops with long generations, such as tomato, pepper, or eggplant. Speed breeding, when integrated with modern tools like marker-assisted selection, greatly enhances the efficiency of vegetable breeding programs and helps meet growing food demands.

Factors of Speed Breeding

- **Photoperiod:** Photoperiod plays a crucial role in speed breeding for vegetable crops by influencing flowering time and overall growth. Short-day or long-day conditions can be manipulated to induce earlier flowering, accelerating the breeding cycle.
- **Temperature:** Temperature plays a crucial role in speed breeding for vegetable crops, influencing plant growth, flowering, and seed set. Optimal temperature ranges accelerate development, shorten breeding cycles, and increase the efficiency of crop improvement.
- **Light quality:** Light quality plays a crucial role in the speed breeding of vegetable crops, as it influences plant growth, development, and flowering time. Different light spectra, including red, blue, and far-red light, can affect photosynthesis, stem elongation, and leaf morphology, ultimately accelerating crop cycles.
- **Light intensity:** Light intensity plays a crucial role in speed breeding vegetable crops by influencing photosynthesis and growth rates. Higher light intensity accelerates plant growth, leading to faster development and earlier flowering, which are essential for breeding cycles.

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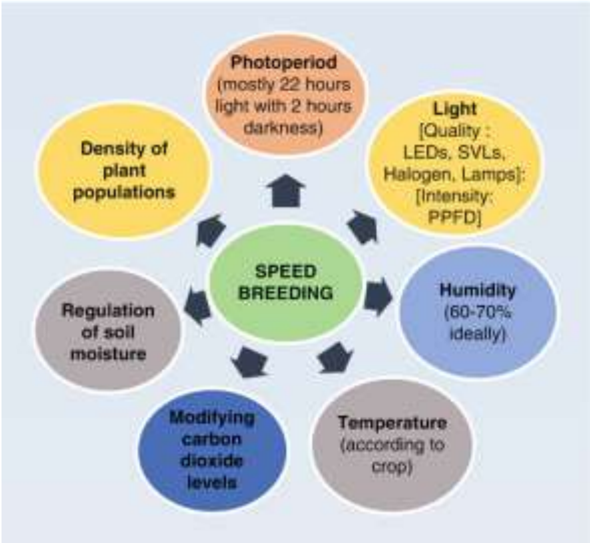
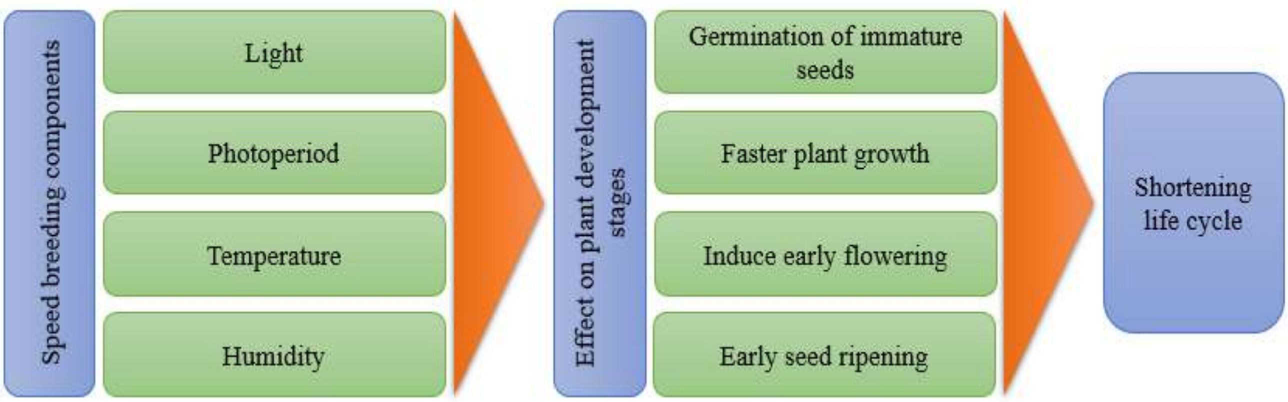


- **Humidity:** Humidity plays a significant role in speed breeding of vegetable crops by influencing plant growth and reproductive processes. High humidity can reduce water loss through transpiration, which may promote faster vegetative growth but can also lead to increased susceptibility to diseases.
- **CO_2:** CO_2 enrichment plays a significant role in enhancing the speed of breeding in vegetable crops. Elevated levels of CO_2 improve photosynthesis, leading to faster plant growth and increased yield potential. This facilitates the selection of desirable traits in breeding programs by accelerating the generational turnover.
- **Plant nutrition:** Plant nutrition plays a crucial role in speeding up the breeding process in vegetable crops by enhancing growth rates and improving reproductive efficiency. Optimal nutrient management accelerates physiological processes like flowering and fruiting, leading to quicker selection cycles.
- **Plant hormones:** Plant hormones play a crucial role in speed breeding vegetable crops by regulating growth, development, and stress responses. Hormones like gibberellins, cytokinins, and auxins influence processes such as seed germination, flowering, and fruit set, which are critical for accelerating breeding cycles. By manipulating these hormones, researchers can reduce time needed to develop new crop varieties, enhancing yield, resistance, and adaptability to environmental conditions.

Types of Speed Breeding Setups

1. **Controlled environment chamber:**

Controlled environment chambers are highly effective for speed breeding as they provide precise control over temperature, light, humidity, and CO_2 levels, which can be adjusted to optimize plant growth. These chambers can simulate different seasons or geographical conditions, allowing researchers to accelerate plant breeding cycles. With the ability to maintain stable and reproducible conditions, they help ensure uniform plant growth and reduce environmental variability. Although this setup requires significant investment, it supports year-round breeding and can significantly shorten



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breeding cycles by creating optimal conditions for accelerated plant development.

2. **Glasshouse speed breeding conditions:**

Glasshouses offer a controlled but natural environment for speed breeding, with the ability to regulate temperature, light intensity, and humidity. These setups provide flexibility by using sunlight as the primary light source, reducing operational costs. In glasshouse breeding, artificial lighting is often used to extend photoperiods, ensuring rapid flowering and maturation. They can support large scale experiments while maintaining a balance of natural and artificial environmental control. Glasshouses also offer space efficiency and reduce the need for high energy input compared to controlled environment chambers, making them an attractive option for plant breeders.

3. **Homemade growth room for low-cost speed breeding:**

Homemade growth rooms offer a cost-effective alternative to commercial setups for speed breeding. These can be constructed in small spaces, such as basements or garages, and are equipped with grow lights, fans, and heaters to mimic controlled conditions. While not as precise as controlled chambers or glasshouses, they allow for flexibility and affordability. Homemade growth rooms are particularly useful for small-scale breeders or those working with limited resources. With proper planning, they can provide an effective solution for accelerating plant breeding, though they may require regular monitoring and adjustments.

Fig.: Integration of speed breeding with other modern plant breeding technologies

- **Speed breeding capsules:** Speed breeding capsules are innovative tools designed to accelerate plant breeding by creating optimal growth conditions for rapid crop development. These capsules use controlled environmental factors, such as light, temperature, and humidity, to significantly shorten the breeding cycle. The technology is particularly beneficial for developing crops with improved traits, such as disease resistance and yield. By enhancing photosynthesis and promoting faster growth, speed breeding capsules enable researchers to produce multiple generations in a shorter period. This method is revolutionizing agricultural research, enabling faster crop improvement.

List of vegetable crops where speed breeding was implemented in crop improvement

Crop	**Techniques**	**Days to flowering**	**No. of gen/year**	**Reference**
Tomato	Photoperiod	60-70	5-6	Velez-Ramirez *et al.*, 2014
Onion	Bulb dormancy breakdown, photoperiod with far-red light, temperature	50-70	2-3	Khosa *et al.*, 2016
Potato	Long photoperiod	70-90	2-3	Sood *et al.*, 2020

Amaranth	Photoperiod and temperature	28	6	Stetter *et al.*, 2016
Faba bean	Plant hormones, photoperiod, light intensity, and immature seed	29-32	7	Mobini *et al.*, 2015
Pea	Plant hormones, photoperiod, and immature seed germination	33	5	Mobini and Warkentin, 2016
Brassica oleracea	22-hour photoperiod	108	-	Ghosh *et al.*, 2018
Brassica napus	22-hour photoperiod	87	-	Ghosh *et al.*, 2018
Brassica rapa	22-hour photoperiod	87	-	Ghosh *et al.*, 2018
Chilli	Photoperiod, Light intensity	38-40	4	Liu *et al.*, 2022

Challenges of speed breeding:

- High energy costs
- Limited infrastructure
- Reduced seed quality
- Nutrient imbalances
- Pest and disease management
- Stress response misinterpretation
- Crop-specific protocols
- Regulatory and biosafety concerns

Conclusion:

Speed breeding in vegetable crops represents a transformative approach to accelerating genetic improvement and meeting global food demands. By enabling multiple crop generations per year under controlled environmental conditions, it significantly reduces the time required for variety development. This technique, when combined with tools like marker-assisted selection and genomic technologies, enhances the precision and efficiency of selecting desirable traits such as disease resistance, stress tolerance, and improved nutritional quality. It also supports rapid response to emerging biotic and abiotic challenges in vegetable production. Speed breeding does face several limitations, including high infrastructure costs, crop-specific optimization requirements, and challenges in replicating field-like conditions. However, ongoing advancements in controlled-environment agriculture, energy-efficient technologies, and crop-specific protocols continue to improve its feasibility. With proper integration into breeding programs, speed breeding can play a critical role in developing climate-resilient, high-yielding vegetable cultivars, ultimately contributing to sustainable agricultural practices and food security.

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The Role of Krishi Vigyan Kendra (KVK) in Transforming Rural Agriculture

[1]Dr. Dileep Kumar Gupta, [2]Ashish Kumar Nagar, [3]Dr. Gautam Veer Chauhan

[1]Teaching Assistant, Deptt. of Agricultural Extension, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.) – 284128

[2]Assistant Professor, Department of Agriculture Extension Education Sourabh Agriculture College Kheda Hinduon City Rajasthan

[3]Subject Matter Specialist (Agronomy) ICAR-CRIDA, KVK, Ranga Reddy, Hyderabad

Krishi Vigyan Kendras (KVKs), which are instituted by the Indian Council of Agricultural Research (ICAR), are key to filling the gap between technology generation at research centers and its application in farm settings. Operating at the district level, the KVKs specialize in the assessment of technology, on-farm testing, training, demonstrations, and advisory services to strengthen farmers. They are crucial in promoting increased productivity, climate-resilient agriculture, soil health, and rural employment opportunities through skill development and agripreneurship. In spite of encountering infrastructural as well as operational difficulties, KVKs are still crucial in revolutionizing rural farming and attaining sustainable development objectives. KVKs need to be strengthened for a self-dependent and affluent agriculture community.

Introduction

Agriculture continues to be the backbone of the Indian economy, especially in rural India where most of the population relies on agriculture for livelihood. Though crucial, India's agricultural sector has long been plagued by challenges such as a prevalence of traditional cultivation practices, poor awareness of scientific advances, and restricted access to quality inputs and market information. Together, these challenges have hampered low productivity, low income levels, and rural stagnation.

With the vision to bring the gap between technology and knowledge generated in agricultural research institutions and farmers, the Indian Council of Agricultural Research (ICAR) conceived and initiated Krishi Vigyan Kendras (KVKs). The major function of KVKs is to act as district-level extension centers for disseminating location-specific technologies and training among farmers by adopting a practical approach. DAC & FW 2020.

India currently has over 730 KVKs functioning in all agro-climatic zones as of 2025. These KVKs serve as drivers of rural change by carrying out On-Farm Testing (OFT), Frontline Demonstrations (FLDs), and capacity development programs. They emphasize the development of farmers', rural youth, and extension personnel's knowledge and skills. KVKs also promote innovations in seed varieties, pest management, water use efficiency, integrated nutrient management, climate-resilient practices, and value addition. Acharya *et.al.* 2019.

By direct farmer involvement and input, KVKs facilitate the development of technologies suited to specific local requirements and the encouragement of sustainable farming. They are crucial to the realization of national objectives concerning food security, farmers' income augmentation, and rural development, thus playing a crucial role in India's agricultural revolution process.

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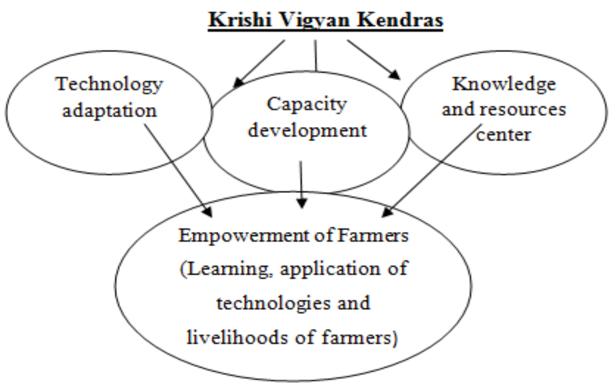

Source: https://www.biotecharticles.com

2. Krishi Vigyan Kendra Objectives

- Technology Assessment and Demonstration: To evaluate and demonstrate new farm technologies directly on farmers' fields.
- Capacity Building: To develop farmers, rural youth, and extension workers on various farming methods.
- Advisory Services: To impart timely agricultural advice and problem-solving solutions to farmers.
- Knowledge Resource Centre: To act as a center for sharing agricultural knowledge and information.
- Promotion of Sustainable Practices: To promote climate-resilient and sustainable farming techniques.
- Entrepreneurship Development: To promote agripreneurship through skill development and vocational training.

3. Core Activities of Krishi Vigyan Kendras (KVKs)

Krishi Vigyan Kendras carry out a range of need-based activities for widespread promotion of scientific agriculture. These activities are field-tested, farmer-driven, and intended for productivity, sustainability, and income increases. The main activities are: Saha *et.al.* 2025.

3.1 On-Farm Testing (OFT)

KVKs implement On-Farm Testing to evaluate the performance and suitability of newly created agricultural technologies under actual farm conditions. The trials assist in the verification of research results and the creation of location-specific solutions, which become more accepted and feasible for farmers.

Source: anskritiias.com

3.2 Frontline Demonstrations (FLD)

FLDs are carried out to show the effectiveness of upgraded technologies like high-yielding varieties, integrated pest and nutrient management, and conservation practices directly on farms. Demonstrations provide visible evidence of increased yield, profitability, and efficiency in resource use and hence promote large-scale adoption.

3.3 Training Programs

KVKs carry out formal training programs for:

- Farmers and Farm Women: Topics cover crop management, soil health, irrigation methods, control of pests and diseases, and organic farming.
- Rural Youth: Specialized vocation training in beekeeping, mushroom culture, dairy, poultry, and agri-entrepreneurship.
- Extension Personnel: Capacity upgradation regarding recent developments in agriculture to enable efficient last-mile reach.

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3.4 Advisory and Diagnostic Services

KVKs extend customized advisories through mobile applications, WhatsApp groups, help desks, and farm visits. They also employ ICT tools to share real-time solutions for farming issues.

3.5 Seed and Input Production

KVKs engage in seed and seedling production and supply of quality seeds, biofertilizers, vermicompost, and plant protection products. This eliminates farmers' reliance on expensive or untrustworthy market sources.

3.6 Soil and Water Testing

With provision of soil health and water quality analysis, farmers adopt balanced fertilizer application and wise water utilization, maintaining long-term soil fertility and sustainability.

4. Role in Rural Agricultural Transformation

Krishi Vigyan Kendras (KVKs) have been instrumental in the transformation of rural agriculture by taking scientific developments to the doorstep of the farmer. Through specific interventions and locally adaptive approaches, KVKs help in the improvement of productivity, sustainability, and livelihood security in the countryside.

4.1 Technology Dissemination

KVKs serve as bridges for the delivery of the newly developed agricultural technologies at the research institutes to the fields of farmers. They are better crop varieties, pest and disease management options, resource conservation technologies, and newer tools. Farmer trainings and on-farm demonstrations by KVKs enable greater awareness, confidence, and adoption by farming communities and, in turn, increased productivity and income.

4.2 Bridging the Research-Extension-Farmer Gap

One of the most important roles played by KVKs is in bridging agricultural research, extension services, and farmers. These are an interface platform where scientists can see field-level feedback, and farmers provide local experiences and issues. This feedback mechanism is two-way, such that research is aligned with farmers' needs, and agricultural innovations are more effective and location-specific.

4.3 Improving Livelihood Opportunities

KVKs provide vocational training and skill development for rural women and youth, imparting them the skills to establish income-generating ventures such as dairy, mushroom culture, poultry, and beekeeping. The programs have resulted in an increase in agripreneurs, minimized rural unemployment, and enhanced the economic living standards of rural families.

4.4 Climate Smart Agriculture

Under climate uncertainty, KVKs encourage climate-resilient farming practices like drought-resistant crops, conservation tillage, efficient irrigation techniques (e.g., drip and sprinkler), and integrated nutrient and pest management. These methods enable farmers to avoid climate hazards while maintaining productivity and natural resource conservation.

4.5 Empowering Women Farmers

KVKs focus on the participation of women in farming by conducting women-specific training programs, stimulating nutrition-sensitive agriculture, and facilitating home-based agro-enterprises. Empowering women not only increases incomes at the household level but also enhances nutrition and decision-making at the rural household level.

5. Success Stories and Case Studies

Krishi Vigyan Kendras (KVKs) have provided many success stories throughout India over the years, not only revolutionizing agricultural output but even the socio-economic status of rural areas. These case studies identify the affirmative impact of KVK-led interventions. Singh *et.al.* 2023.

5.1 Doubling Farmers' Income

KVKs in Maharashtra, Punjab, and Karnataka have successfully adopted integrated farming systems (IFS)—integrating crop cultivation with dairy, poultry, fisheries, and horticulture. Through cost reduction in inputs and assured year-round income, farmers have been able to double their income in a few years. For example, KVK Baramati sensitized farmers to precision farming, such as fertigation and drip irrigation, that enhanced water efficiency and crop yields drastically.

5.2 Popularization of New Varieties

By organizing Frontline Demonstrations (FLDs), KVKs have promoted stress-tolerant and high-yielding varieties such as Pusa Basmati 1121, HD 2967 wheat, and horticultural crops under the PM-KUSUM scheme. Such improved varieties have been popular among farmers for their high productivity, market price, and compatibility with local agro-climatic conditions, particularly in Haryana, Uttar Pradesh, and Tamil Nadu.

5.3 Soil Health Management

KVKs have played a vital role in encouraging the adoption of Soil Health Cards (SHC) and soil and water testing campaigns. Tailor-made nutrient application programs suggested by KVK specialists have resulted in effective use of fertilizers, improved cost savings, and enhanced soil fertility. Farmers have seen as much as 15–20% increases in yield in crops such as paddy and maize using this scientific method.

5.4 Agripreneurship Promotion

KVKs have empowered women and rural youth through training in direct marketing, organic farming, branding, packaging, and agri-processing. This has resulted in the development of rural entrepreneurs who are successful and making products such as millet snacks, organic honey, and processed fruits, providing jobs and stimulating rural economies.

6. Challenges Encountered by Krishi Vigyan Kendras (KVKs)

Despite their crucial position in agricultural development in rural areas, KVKs experience various operational and systemic issues that constrain their potential. Sahoo *et.al.* 2021.

Human Resource Shortages continue to be a serious problem. Most KVKs work with vacancies, particularly Subject Matter Specialists (SMS), which encumbers the provision of expert training, demonstrations, and technical advice. Funding Restraints also affect their operations. Insufficient operational budgets limit the number and quality of on-farm demonstrations, training programs, and field visits. This further influences the outreach and visibility of KVK activities.

Infrastructure Lapses, e.g., obsolete laboratories, insufficient training halls, and insufficient demonstration units, impede sound knowledge sharing and farmer participation in many districts. Connectivity Challenges in tribal and remote regions are a significant challenge to the provision of digital extension services. The limited availability of the internet and ICT technology impedes timely communication with farmers.

Finally, Lack of Convergence and coordination among state agricultural departments, NGOs, and private sector actors results in duplication of work and ineffective utilization of resources.

7. Recommendations and Way Forward

In order to further improve the influence of Krishi Vigyan Kendras (KVKs) on rural agriculture transformation, there is an immediate need to rectify their current constraints and tap into available opportunities through strategic reforms. The following suggestions can assist in building up the KVK system: Singh *et.al.* 2021.

1. Infrastructure Strengthening

Most KVKs need extensive strengthening in physical infrastructure like soil testing laboratories, meteorological stations, smart classrooms, training halls, and demonstration plots. Investment in sophisticated tools and mechanized equipment can also improve the efficiency of practical training and farmer participation.

2. Digital Extension

In the age of smart farming, KVKs have to embrace ICT-based tools, artificial intelligence (AI), mobile applications, and digital platforms for more extensive and accelerated dissemination of knowledge. Weather advisories, pest warnings, and crop care tips in real time through WhatsApp, SMS, or special apps can significantly enhance outreach, particularly in remote areas.

3. Public-Private Partnership

Partnership with private firms, agri-tech start-ups, and NGOs can enhance availability, technical knowledge, and access to input and output markets. Custom hiring centers, input supply chains, and digital literacy campaigns can be facilitated. PPP models can also enhance facilitation of FPOs.

4. Farmer Producer Organizations (FPOs)

KVKs need to be proactively connected with FPOs to facilitate aggregation, mitigate post-harvest losses, enhance access to credit and insurance, and improve market competitiveness. Joint demonstrations and trainings with FPOs can help accelerate uptake of scientific practices at a larger farmer base.

5. Policy Support

Strong policy interventions are needed to provide sufficient funding, timely resource allocation, and performance-linked incentives for high-performing KVKs. Special innovation grants, infrastructure grants, and backward region grants can make KVKs more resilient and responsive.

With these forward-looking approaches, KVKs can remain catalytic institutions in achieving the vision of sustainable agriculture, rural empowerment, and food security in India.

8. Conclusion

Krishi Vigyan Kendras are dynamic institutions that directly contribute to rural agricultural change by empowering farmers with science-based information, skills, and confidence. Their value addition to self-reliant agriculture, employment, climate resilience, and food security cannot be measured. To be able to maximize their potential, sustained investment, innovation, and linking with national development priorities must continue.

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Water Conservation Techniques in Agriculture

[1]Dr. E.Shirin Hima Bindu, [2]Dr. Abha Nutan Kujur, [3]Dr. Ashutosh Kumar, [4]Dr. Subhash Verma

[1]Assistant professor, College of Community Science, PJTAU

[2]Birsa Agricultural University Ranchi, Jharkhand

[3]SMS, Horticulture, Vegetables Krishi Vigyan Kendra, Narkatiyaganj, West Champaran, RPCAU, Pusa, Bihar.

[4]Assistant Professor, School of Agriculture, Eklavya University, Damoh, Madhya Pradesh

Water is a fundamental resource for agricultural productivity, yet increasing water scarcity caused by overextraction, erratic rainfall, deforestation, and climate change poses a critical threat to food security and rural livelihoods. In India, agriculture consumes over 80% of freshwater, yet traditional irrigation methods result in low water use efficiency. Sustainable water conservation techniques are essential to address this crisis by minimizing water waste, improving soil moisture retention, and increasing irrigation efficiency.

This bulletin highlights major water-saving techniques such as rainwater harvesting, mulching, drip and sprinkler irrigation, contour farming, drought-tolerant crops, soil moisture management, and construction of farm ponds and check dams. It also emphasizes crop-based irrigation scheduling and reduced tillage as climate-resilient strategies. The adoption of these methods results in multiple benefits including increased crop yield and quality, reduced input costs, improved soil health, and enhanced sustainability of farming systems.

Effective water conservation not only boosts productivity and profitability but also strengthens farmers' resilience to climate variability. Recommendations include regular soil moisture monitoring, promotion of organic farming, participation in capacity-building programs, and collaboration with Krishi Vigyan Kendras (KVKs) for on-farm demonstrations. Empowering farmers with water-saving knowledge and technologies is crucial for achieving sustainable and climate-resilient agriculture.

Introduction

Water is the building block of agricultural productivity, serving a vital function in crop development, livestock husbandry, and general farm activity. Yet in the last several decades, the escalating water crisis, driven by groundwater over-extraction, irregular and inconsistent rainfalls, forest destruction, and the mounting effects of climate change, has become a compelling issue for farmers worldwide. For example, in India, more than 80% of fresh water is utilized for agriculture, but water efficiency is low as a result of traditional methods of irrigation and inefficient management of water.

The impending danger of water shortage not only jeopardizes food safety but also brings unprecedented pressure upon ecosystems and rural economies. So adopting effective and sustainable water saving methods is no longer a choice, but a necessity. These methods seek to minimize water waste, optimize soil water retention, maximize irrigation efficiency, and render agriculture resilient to climate change.

Conserving water in agriculture is as much a matter of saving water as it is of maximizing the efficiency of resource use, maximizing the economic benefits for farmers, and providing long-term sustainability of farming systems. It involves both traditional folklore

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and current technology—everything from mulching and contour tillage to micro-irrigation and rainwater harvesting.

With the realities of climate change and the rising need for food, ensuring that there is water conservation has become an imperative. Giving farmers the ability to save water with knowledge, tools, and assistance can ensure that the future of farming is secured for generations to come.

Major Water Conservation Methods in Agriculture

Integrated water management in agriculture demands a comprehensive strategy, embracing a wide range of techniques that not only minimize water consumption but also improve its supply and efficiency. The following are some of the most common and efficient methods:

Rainwater Harvesting is the orderly collection and storage of rain water from rooftops, farm bunds, or natural catchment. It greatly decreases the dependency on groundwater and constitutes a vital source of water for irrigation during dry periods, especially in areas prone to drought. It also helps improve the water supply and recharge local aquifers.

Mulching refers to the act of covering the ground surface with organic or inorganic materials like crop residues, straw, leaves, or plastic sheets. Mulching suppresses weed growth, lowers soil temperature ranges, and inhibits water evaporation from the soil, thus saving soil moisture and improving soil health.

Drip Irrigation is a micro-irrigation technique that gradually delivers water directly to the root system of plants using a system of pipes and emitters. Drip Irrigation reduces water loss through surface runoff and evaporation, increases the efficiency of water use by as much as 90%, and achieves maximum plant growth under minimal water supply.

Sprinkler Irrigation employs a network of pressurized pipes and revolving nozzles for the distribution of water uniformly across the field, mimicking natural rainfall. The technique allows uniform water application with great ease over undulating ground and sandy soils. It minimizes the losses by deep percolation and maintains the balance of soil moisture.

Contour Farming and Terracing are management practices applied to sloping lands. Contour farming is done by plowing along the slopes, and terracing involves creating step-like fields to decelerate water flow. Both methods slow surface runoff, avoid soil erosion, and enhance water penetration into the land.

Use of Drought-Resistant Crop Varieties is a management strategy to adapt to water scarcity through the use of crops that have lower water requirements and are drought-tolerant. Crops like millets, chickpeas, pigeon peas, and some improved hybrids can grow in moisture-stressed conditions, providing stable yields while minimizing irrigation requirements.

Soil Moisture Conservation Practices involve a variety of agronomic practices like deep plowing, crop rotation, green manuring, and having high organic matter content of the soil. These practices increase the water-holding capacity of the soil, lower evaporation from the soil surface, and favor improved root growth.

Farm Pond and Check Dam Construction offers physical infrastructure to harvest surplus rainwater for later use. Farm ponds trap surface runoff on the farm, while check dams retard the flow of streams to permit infiltration and storage. These structures aid supplemental irrigation, livestock watering, and groundwater recharge during dry periods.

Crop-based irrigation scheduling requires giving water according to the growth stage of the crop, soil water content, or weather prediction. Various instruments like moisture sensors, tensiometers, and agrometeorological alerts assist growers in optimizing irrigation timing and quantity, consequently minimizing wastage and maximizing productivity.

Zero or Minimum Tillage Adoption minimizes soil disturbance and maintains the natural structure and organic matter of the soil. The practice slows down the rate of water evaporation from the soil, increases the infiltration of rainwater into the soil, and creates long-term drought and climate variability resilience.

Advantages of Agriculture Water Conservation

Use of water conservation methods in agriculture has numerous advantages that extend well beyond water savings alone. These advantages help ensure the long-term sustainability, profitability, and resilience of agricultural operations:

Increases Water Use Efficiency

Water conserving methods guarantee that each drop of water is utilized efficiently and ends up where it is needed most the root zone of the plant. Methods such as drip irrigation, mulching, and moisture-based irrigation scheduling enhance optimal water application with minimized loss through evaporation, runoff, or deep percolation. This translates to more efficient use of water, particularly in water-deficient areas.

Increases Crop Yield and Quality

Continuous and sufficient moisture supply, facilitated by sound water management, is conducive to healthy plant development and growth. This leads to enhanced crop yields and product quality. For example, drip irrigation is known to enhance fruit size, sugar level, and shelf life in horticultural products.

Reduces Input Costs and Energy Use

By minimizing the amount of water and how often it is irrigated, water conservation methods reduce input costs in terms of fuel, electricity, and labor. Low-energy irrigation systems like sprinkler and drip also decrease energy usage during water pumping, thus saving operational cost and carbon emissions.

Keeps Soil Healthy

Over- or inefficient irrigation usually causes waterlogging, salinization, and nutrient leaching, which reduce soil structure and fertility. Conservation of water maintains an optimal level of soil moisture, conservation of organic matter, and promotion of favorable microbial activities, all of which are paramount in maintaining soil health.

Contributes to Sustainability of Farming Systems

The use of water-conserving methods renders agriculture more adaptive to climate change, drought, and variable rainfall. It ensures the sustainable management of natural resources so that generations to come will still have fertile lands and sufficient water. In addition, these methods ensure environmental preservation by conserving groundwater and preserving the equilibrium in the ecosystem.

Supports Climate Change Adaptation

Water use efficiency in agriculture helps mitigate climate change through reduction of greenhouse gas emissions that come with over-irrigation and pumping. It also enhances farmers' adaptive capacity to respond to unpredictable weather patterns, extended dry spells, and changing rainfall regimes.

Enhances Livelihood Security

Finally, water conservation assists farmers in stabilizing and raising their incomes by means of improved yields, lower costs, and better quality of produce at the market. It also lowers the danger of crop failure under periods of water stress, hence providing food and income security for farming households.

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Recommendations to Farmers

For effective water conservation and sustainable farming, farmers are recommended to implement the following measures:

Check Soil Moisture Periodically

Monitoring soil moisture levels periodically with simple instruments such as tensiometers, soil moisture probes, or even by hand can enable farmers to irrigate only when required. This prevents over-irrigation and supplies water to crops depending on actual field conditions.

Adopt Organic Farming Practices

The addition of organic matter like compost, green manure, and crop residues enhances soil structure and its water-holding capacity. Organic farming practices also minimize the use of chemical inputs, rendering the soil more drought- and extreme weather-resistant.

Attend Training on Water-Saving Technologies

Agriculturists must engage in KVK-organized training programs, workshops, and exposure trips by NGOs, government agencies, or Agricultural Universities. The programs offer practical information on new methods of irrigation, water-saving crop planning, and eco-friendly water management.

Partner with KVKs and Extension Services for On-Farm Demonstrations

Interaction with local KVKs, field experts, and extension officers in agriculture allows farmers to experience on their own farms the feasibility of water-saving methods such as drip irrigation, mulching, and rainwater harvesting. These partnerships also ensure access to subsidy schemes, technical advice, and better farm planning.

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KVK's Contribution to Doubling Farmers' Income

Rita Fredericks
CEO, Precision Grow (A Unit of Tech Visit IT Pvt Ltd)

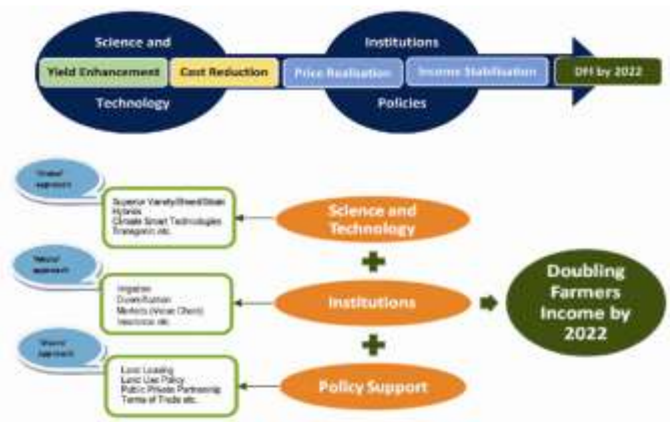
Krishi Vigyan Kendras (KVKs) are crucial for realizing the national objective of doubling farmers' income through technology transfer, skill enhancement, and entrepreneurship development. Working under ICAR, KVKs function as frontline extension systems linking research and rural systems. KVKs improve crop productivity, encourage integrated farming systems, develop allied activities, and enable agri-startups. By offering timely advisories, value addition training, and institutional linkages, KVKs bring sustainable and diversified income streams to farmers. Based on some challenges, however, beefing up KVK infrastructure and digital agriculture promotion can further increase their contribution towards rural livelihood and agricultural change.

1.Introduction

Doubling Farmers' Income (DFI) by 2022 was a bold and revolutionary target declared by the Government of India in 2016. The programme would raise the standard of living for millions of Indian farmers by raising profitability, lowering input expenses, fostering sustainable agriculture, and generating new sources of income outside farming. This goal focused not only on enhancing production of crops but on promoting economic success and overall development in rural regions.

To meet this multifaceted objective, it was necessary to have a holistic strategy that included increasing crop productivity, optimal use of resources, improved access to markets, value addition, allied sector diversification, and embracing new technologies. In this regard, Krishi Vigyan Kendras (KVKs) have become key institutions facilitating this vision. Functioning under the aegis of the Indian Council of Agricultural Research (ICAR), KVKs are farm-level agricultural extension institutions located in nearly every district of India. Their role is to convert scientific farm research into actionable field-level solutions specifically suited to local conditions. **Chand *et.al.* 1017.**

KVKs serve as a go-between bridge linking research institutions with farmers. They are capable of conducting on-farm trials, frontline demonstrations, and capacity development programs to accelerate region-specific technologies and practices. In this way, they enable farmers to adopt new cultivation methods, sustainable resource management, and innovative farming systems. In addition, KVKs contribute in a substantial way to entrepreneurship development, skill training for rural youth, and development of allied sectors such as dairy, poultry, and beekeeping, as well as market linkages.With a combination of advisory services, training, demonstrations, and electronic outreach, KVKs facilitate last-mile delivery of agricultural technologies. As their contribution to hastening technology uptake, fostering integrated farming, and connecting farmers with government programs has rendered them invaluable in the national plan for farmers' income doubling as well as rural prosperity.



2. Core Functions of KVKs Facilitating Income Improvement

Krishi Vigyan Kendras (KVKs) play a crucial role in converting agro-research into farm-level gains. Their major functions are aimed at directly or indirectly enabling income augmentation through technology delivery, skill building, entrepreneurship development, and real-time advisory services. The following are the major functional areas through which KVKs enable doubling of farmers' income: Rajendran *et.al.* 2016.

2.1. Technology Assessment and Demonstration

KVKs have a key role to play in evaluating and improving technologies via On-Farm Testing (OFT) and Frontline Demonstrations (FLDs) in actual field conditions. Farmers are able to see the comparative performance of new crop varieties, better agronomic management, integrated pest management, or farm equipment through these tests.

For example, FLDs on better varieties of wheat, rice, and mustard have continued to record 20–30% higher yields than local methods.

Such trials facilitate location-specific adaptation, minimize risks, and enhance farmer confidence for the adoption of innovations.

2.2. Capacity Building and Skill Development

KVKs conduct training programs for farmers, farm women, rural youth, and extension functionaries. These are intended for both core and allied sectors of agriculture.

The most popular skill-based training is bee keeping, mushroom culture, dairy management, vermicomposting, organic farming, and others.

Such programmes help farmers diversify income and decrease their dependence on cropping alone.

2.3. Demonstration Units for Encouraging Entrepreneurship

Model demonstration units like seed production farms, nurseries, poultry units, food processing units, and vermicompost pits are organized by KVKs.

- They are live demonstration labs, which inspire rural youth and women to take them up as micro-enterprises.
- They also show cost-benefit details, which help enterprising decisions.

2.4. Advisory Services and Digital Outreach

KVKs provide timely location-based advisory services through various media such as Kisan Mobile Advisory Services (KMAS), WhatsApp groups, toll-free telephones, mobile applications, and social media.

- Advisories on pest infestation, fertilizer application timing, irrigation scheduling, and market information enable farmers to minimize losses and make better decisions.
- KVKs' last-mile connectivity is improved by digital tools and enabled with real-time support.

3. Key Areas of Intervention for Doubling Income

In order to make an effective contribution towards doubling farmers' income, Krishi Vigyan Kendras (KVKs) conduct focused interventions in different areas. These are beyond improvement in yield and cover comprehensive agriculture development related to productivity, diversification, allied sectors, and entrepreneurship. DAC &FW 2018.

3.1. Improvement in Crop Productivity

Crop productivity improvement is still a prime objective of KVKs. It is done by encouraging high-yielding, disease-tolerant, and climate-tolerant crop varieties with better adaptability to local agro-climatic conditions. Moreover, KVKs also promote

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site-specific nutrient and water management technologies, which enhance efficiency in the use of resources and minimize costs of inputs. Precision farming, micro-irrigation systems such as drip and sprinkler, and conservation technologies like zero tillage and laser land leveling have greatly enhanced productivity and profitability.

3.2. Diversification and Integrated Farming Systems (IFS)

KVKs propagate actively Integrated Farming Systems (IFS) that incorporate crops with horticulture, livestock, fishery, agroforestry, and vermicomposting. This method not only guarantees multiple income streams but also enhances recycling of nutrients, risk reduction, and full-time employment.

Example: In Bihar, a farmer trained under the IFS model by the KVK raised his yearly income from ₹60,000 to ₹1.5 lakh on only 1 hectare by incorporating vegetables, poultry, and dairy.

3.3. Value Addition and Allied Sectors

Technical assistance for allied enterprises such as poultry, piggery, dairy farming, beekeeping, and aquaculture is offered by KVKs, which are profitable sources of income. Value addition, processing, and branding of farm produce (e.g., jam, pickles, millets) are promoted by them to increase market value. Training in labelling, packaging, and agri-exhibition is provided to farmers so that they can sell their produce better.

3.4. Rural Entrepreneurship and Agri-Startups

KVKs are turning into rural agri-business incubators, motivating youngsters to think about agriculture as a business. They assist farmers in availing schemes such as PM-FME, Startup India, and Atma Nirbhar Bharat, encouraging rural entrepreneurship and economic independence.

4. Case Studies: Impact of KVK Interventions

The actual power of Krishi Vigyan Kendras is their field-level influence and capacity to bridge research with tangible socio-economic benefits. Various success stories across India's regions demonstrate how KVK interventions have resulted in significant income augmentation through improved crops, integrated farming, value addition, and digital extension. Annual Report 2020–21.

4.1. KVK Guntur, Andhra Pradesh – Improving the Value Chain of Chilli

At the district level of Guntur, KVK released a disease-tolerant, high-yielding chilli variety through Frontline Demonstrations (FLDs). Simultaneously, farmers were also imparted training in value addition methods like the preparation of chilli flakes and powder, as well as general training in hygiene, packaging, and branding.

Effect: Intervention created a Farmer Interest Group (FIG), which established a micro chilli processing unit. Farmers benefited not only from increased yields but also reaped greater market value. Income was raised substantially from ₹1.2 lakh/ha to ₹2 lakh/ha through value-added marketing.

4.2. KVK Sehore, Madhya Pradesh – Integrated Farming System (IFS) Model

KVK Sehore adopted an Integrated Farming System model involving crop farming along with dairy, poultry, and vermicompost farming. There was focus on recycling of nutrients, fodder management, and waste disposal.

A smallholder farmer following IFS on 1 hectare experienced income increase from ₹50,000 to ₹1.8 lakh per annum. Recycling of resources not only saved cost but also brought income from diverse sources year-round.

4.3. KVK Baramati, Maharashtra – Making Use of Digital Extension

KVK Baramati adopted digital technologies like mobile advisories, drone spraying, and market intelligence systems to provide real-time advice to farmers.

Impact: Farmers realized 20% savings in cultivation expenses through optimizing the use of inputs. Digital coordination for structured marketing enhanced bargaining power and selling prices, resulting in improved profitability.

5. Policy Linkages and Institutional Support

Krishi Vigyan Kendras (KVKs) are the important convergence points where different government schemes and institutional programs can be implemented effectively, so that technological improvements and gains trickle down to the grassroots level. As mediators between policy guidelines and farming people, KVKs enhance the outreach of public investment in agriculture.

Facilitating Government Schemes

KVKs are proactively involved in facilitating and propagating notable central and state-level schemes that target enhancing agricultural income, risk management, and infrastructure. They include:

- Pradhan Mantri Kisan Samman Nidhi (PM-KISAN): Facilitating notification to registered farmers about their rights and helping them with registration.
- Pradhan Mantri Fasal Bima Yojana (PMFBY): Creating awareness about crop insurance and helping farmers through processes of claiming.
- Rashtriya Krishi Vikas Yojana (RKVY) and ATMA (Agricultural Technology Management Agency): Organizing training programs, demonstrations, and capacity-building activities under project funds.
- Soil Health Card Scheme: KVKs perform soil tests and provide individualized soil health cards with fertilizer advice.
- Extension of Neem-coated urea, high-yielding seed varieties, and Farm Machinery Banks is also facilitated by KVKs, lowering input expenses and enhancing productivity.

Institutional Collaborations

To enhance their outreach and influence, KVKs have collaborated strategically with a diverse array of institutions:

- NABARD: Partnership to promote Farmer Producer Organizations (FPOs), agribusiness models, and rural credit access.
- Private Agri-Tech Startups: MoUs for the promotion of digital agriculture tools, mechanization, and data-driven advisory services.
- Non-Governmental Organizations (NGOs) and Self-Help Groups (SHGs): Joint ventures on gender-sensitive training, women empowerment, and social inclusion in extension programs.

6. Challenges Faced by KVKs

Although Krishi Vigyan Kendras (KVKs) have immensely helped achieve agricultural change and income growth, they are still burdened with numerous structural and functional limitations. These constraints limit their ability to contact every farmer and expand successful technologies across districts. Singh *et.al.* 2020.

1. Limited Infrastructure and Manpower

The majority of KVKs function with minimal physical infrastructure and insufficient human resources, and it becomes challenging to serve large rural populations residing in several villages. The growing demand for diversified services from crop advisory to entrepreneurship training necessitates extra skilled manpower, sophisticated labs, training halls, and mobility support.

2. Insufficient Finance for Technology Demonstration

Most of the KVKs have budgetary limitations that hinder the conduct of mass Frontline Demonstrations (FLDs), On-Farm Trials (OFTs), and entrepreneurship development units. They do not have enough funds to support demonstration plots, acquisition of farm machinery, or the strengthening of training infrastructure.

3. Inadequate Market Intelligence and Linkages

Although KVKs effectively facilitate the adoption of better production technology, they sometimes fail to have strong support mechanisms for post-harvest management, value addition, and market linkage creation. Without adequate access to market information, price projection, or digital commerce platforms, farmers are exposed to market fluctuations.

4. Poor Digital Connectivity in Remote Areas

While KVKs are now making greater use of digital means for outreach and advisory services, inadeququate internet coverage in rural and remote regions constrains the efficiency of mobile-based advisories and e-extension platforms. Such a digital divide impedes the free flow of information in real time among experts and farmers.

7. Recommendations and Way Forward

For fulfilling the complete potential of Krishi Vigyan Kendras (KVKs) in doubling farmers' income as well as in bringing about sustainable agriculture growth, there has to be a strategic roadmap. Below are the suggestions for making the operational efficiency, outreach, and long-term effect of KVKs more efficient:

1. Improve Infrastructure and Human Resources

There is an urgent requirement to enhance current infrastructure such as training halls, soil and plant health labs, and demonstration units. Improved digital connectivity and mobility support are critical for on-time service delivery in rural villages. Moreover, a rise in technical and field personnel will assist KVKs in addressing the increased demand for diversified agricultural assistance.

2. Foster Digital Agriculture

KVKs must embrace innovative tools like Artificial Intelligence (AI), remote sensing, mobile apps, and Decision Support Systems (DSS) to provide real-time, data-driven advice. This will enhance responsiveness and efficiency with improved digital literacy among farmers and smart tools for extension staff.

3. Increase Convergence

Efficient convergence with line departments, R&D institutions, agribusinesses, and financial institutions such as NABARD can increase the outreach and impact of KVKs manyfold. Collaborative models facilitate pooling of resources, prevent duplication, and promote intraregional innovation.

4. Stimulate Participatory Research and Feedback Loops

Farmers need to be engaged in on-farm testing, variety choice, and technology validation so that they remain relevant and responsive. Building farmer feedback into extension programming and policy formulation assists in designing bottom-up models of development that are more participatory and effective.

5. Enhance Entrepreneurship Orientation

KVKs have to play a larger role in nurturing agripreneurs by establishing incubation centers of innovation, rural business incubators, and market guidance cells. This will help rural youth and farm

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families take up income-generation activities other than traditional farming.

8. Conclusion

Krishi Vigyan Kendras have come to play crucial roles of rural transformation. Their multi-faceted role in technology transfer, skill building, value addition, and entrepreneurship development makes them an indispensable partner towards the mission of doubling farmers' income. Through ever-increasing innovation and upgrading their own capabilities, and encouraging participatory modes, KVKs will continue to be the backbone of farmer-led growth in India's agri-economy.

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Persistent Organic Pollutants: A Global Issue

A Anto Rashwin[1*] and K Suganya[2]
[1]Postgraduate Scholar, Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore – 641 003, Tamil Nadu, India
[2]Associate Professor (Env. Science), Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore – 641 003, Tamil Nadu, India

Persistent Organic Pollutants (POPs) are toxic chemicals that pose a significant threat to human health and the global environment. These harmful substances can travel vast distances through wind and water, affecting communities far from their origin. They also persist in the environment for extended periods and accumulate in the food chain, leading to increased concentrations in animals and humans. In this paper, we discuss the dangers of POPs, outline actions taken by various countries, and explain the critical role of the Stockholm Convention in initiating a global effort to reduce or eliminate these pollutants.

Introduction

In our modern world, chemical advancements have brought many benefits. However, some chemicals, known as Persistent Organic Pollutants (POPs), have had serious unintended consequences. POPs are dangerous chemicals that harm people and the environment worldwide. A major concern is their ability to travel long distances, meaning chemicals released in one country can affect distant regions. They also persist for a long time in nature and accumulate in living things, moving up the food chain. To tackle this global challenge, many countries came together to sign the Stockholm Convention in 2001, an important international agreement aimed at controlling these hazardous substances (Stockholm Convention, 2019).

What Are POPs?

POPs are a group of chemicals that were often used in large quantities after World War II in areas like agriculture, disease control, and industry. While some were initially helpful, their long-term effects became clear. POPs can be categorized into two main types:

- **Intentionally Produced:** Chemicals once widely used in farming, disease control, or industrial processes, such as PCBs (found in electrical equipment) and DDT (used for mosquito control).
- **Unintentionally Produced:** Chemicals that are byproducts of industrial processes and burning, like dioxins and furans, often released from waste incinerators.

A well-known group of POPs initially targeted by the Stockholm Convention is often called the "Dirty Dozen" (Mortimer & Reichelt-Brushett, 2023).

Table 1: Common Groups of POPs (Dirty Dozen) and their Sources

POPs	Global Historical Use/Source
Aldrin & Dieldrin	Insecticides (corn, cotton, termites)
Chlordane	Insecticide (crops, lawns, termites)
DDT	Insecticide (agriculture, disease control)
Endrin	Insecticide (cotton, grains, rodents)
Heptachlor	Insecticide (soil insects, termites, crop pests)

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POPs	Global Historical Use/Source
Hexachlorobenzene	Fungicide, industrial chemical, unintentional byproduct
Mirex	Insecticide (fire ants), fire retardant
Toxaphene	Insecticide (crops, livestock), fish killer
PCBs	Industrial processes (transformers, capacitors, paints)
Dioxins & Furans	Unintentionally produced from combustion (waste burning) and industrial processes

Many of these chemicals are no longer produced in developed countries like the U.S., but they remain in the environment, or new POPs are transported from other regions.

The Grasshopper Effect

The Grasshopper Effect, or global distillation, is a process by which Persistent Organic Pollutants (POPs), such as DDT, PCBs, and dioxins, evaporate from warmer regions, travel through the atmosphere, and condense in colder climates, especially the Arctic and Antarctic. Due to their semi-volatile nature, POPs can vaporize under heat, attach to airborne particles, and be carried over long distances by wind. As these air masses reach cooler regions, the pollutants condense and settle on land, snow, or water. During warmer seasons, they may re-evaporate and continue moving further north, repeating this cycle like a "grasshopper" jumping across the globe.

This phenomenon explains how toxic chemicals used or emitted in tropical or temperate areas end up contaminating remote polar environments, where they accumulate in ecosystems and food chains, posing serious risks to wildlife and indigenous communities.

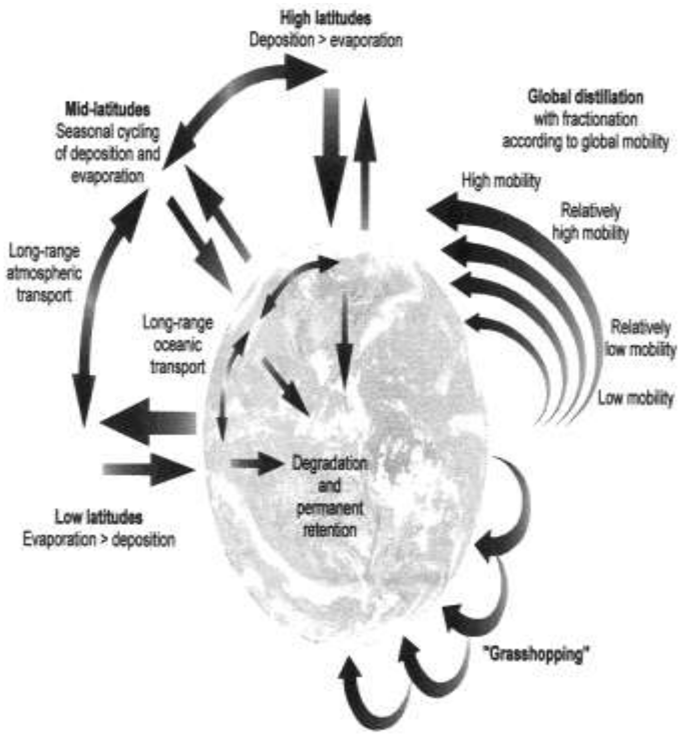

Figure 1: The Grasshopper Effect (Global Distillation) (Vallack *et al.,* 1998)

How Do POPs Affect People and Wildlife?

POPs are dangerous because they accumulate in living organisms, a process known as "biomagnification." This means that as they move up the food chain, their concentration increases theatrically (Kumar et al., 2022). For example, a tiny amount of POPs in water can lead to much higher levels in fish, and even higher levels in birds or mammals that eat those fish. This poses a significant threat to top predators, including humans (Pariatamby & Kee, 2016).

In wildlife, POPs have been linked to declines in populations, diseases, and birth defects in fish, birds, and mammals, such as those observed in the Great Lakes region. These effects in wildlife often serve as an early warning for human health. For humans, exposure to POPs has been linked to various health problems affecting reproductive, developmental, behavioral, neurological, and immune systems. People are mostly exposed through contaminated food, especially those who consume large amounts of fish or wild game. Vulnerable groups include children, the elderly, those with weakened immune systems, and indigenous communities whose diets heavily rely on traditional, locally sourced foods.

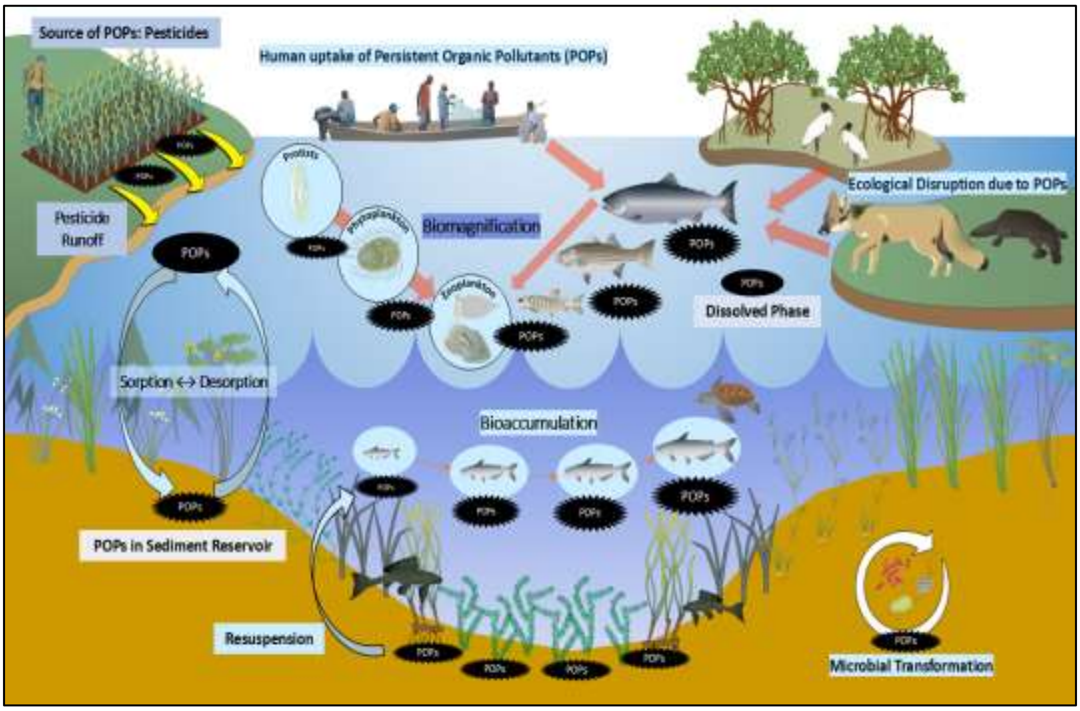

Figure 2: Fate, Transport, and Biomagnification of Persistent Organic Pollutants (POPs) in Aquatic Ecosystems

Domestic and Global Actions to Control POPs

Many countries have taken strong steps to control POPs. The United States, for instance, has banned the production and use of most of the original POPs pesticides and severely restricted PCBs. There have been significant reductions in the release of dioxins and furans from industrial sources. For example, the use of DDT in the U.S. was phased out starting in the late 1960s, leading to the recovery of species like the bald eagle, which were severely impacted by its effects.

Globally, the United States has participated in agreements like the Virtual Elimination of Persistent Toxic Substances in the Great Lakes with Canada and regional action plans under the Commission for Environmental Cooperation (CEC) with Canada and Mexico. The U.S. has also provided substantial financial and technical support to other countries to help them reduce POPs.

The Stockholm Convention on Persistent Organic Pollutants is a landmark global treaty adopted in 2001 and came into force in 2004. Its main goal is to protect human health and the environment from POPs by eliminating or restricting their production and use. The Convention is managed by the United Nations Environment Programme (UNEP).

Even though the United States has not yet fully ratified the Stockholm Convention, it actively participates as an observer and has aligned many of its domestic policies and international cooperation efforts with the Convention's goals, demonstrating a strong commitment to tackling POPs globally.

Conclusion

Persistent Organic Pollutants remain a serious global challenge due to their persistence, ability to travel across borders, and harmful effects on living organisms. The impacts of POPs on both human health and ecosystems, especially in vulnerable regions like the Arctic, stresses the urgent need for concerted global action. The Stockholm Convention serves as a critical international framework, uniting nations in their efforts to eliminate or significantly reduce these dangerous chemicals. Through ongoing research, strict regulations, international cooperation,

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and financial support, the world continues its vital journey towards a future free from the burden of Persistent Organic Pollutants, safeguarding health and the environment for generations to come.

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Biofortification of Staple Crops: Fighting Hidden Hunger Through Smarter Farming

Akino A.[1], R. Jeyajothi[2], S. Shakila[3], S. B. Akshaya[4] and N. Vinothini[5]

[1]Department of Fruit Science, [2]Department of Agronomy, [3]Department of Floriculture and Landscape Architecture, [4]Department of Plant Pathology and [5]Department of Seed Science and Technology, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu Dt – 603 201, Tamil Nadu, India.

Nearly **one in three people** in the world lacks access to adequate nutrition, the solution may not lie in growing more food but in growing smarter food.

Biofortification a groundbreaking agricultural approach that enhances the nutritional value of staple crops like rice, wheat, maize and cassava. Rather than relying solely on pills or processed foods to fix global malnutrition, scientists are now building nutrition into the crops themselves.

What is Biofortification?

Biofortification is the process of **increasing the density of vitamins and minerals** in food crops through conventional breeding, genetic engineering, or agronomic practices. The aim is to make everyday food naturally richer in nutrients like:

- **Iron** (to combat anemia)
- **Zinc** (for immunity and growth)
- **Vitamin A** (to prevent blindness and infections)

Unlike food fortification (which adds nutrients during processing), biofortification enriches the plant as it grows making it a cost-effective and sustainable way to improve diets, especially in rural areas where people rely heavily on locally grown staples.

Why It Matters

According to the World Health Organization, **"hidden hunger"** a form of malnutrition caused by micronutrient deficiencies affects over **2 billion people** worldwide. This type of hunger doesn't always show up as starvation, but it weakens immune systems, stunts growth in children, and reduces productivity.

Biofortification targets this crisis directly by delivering essential nutrients **without changing people's eating habits**. Farmers grow the same crops, but these crops now come loaded with nutritional value.

Success Stories

Several biofortified crops are already making a difference:

- **Orange-fleshed sweet potatoes** rich in vitamin A are being grown across sub-Saharan Africa.
- **Iron-fortified beans** are thriving in Rwanda and Uganda, helping reduce anemia in women and children.
- **Zinc-enriched rice and wheat** are improving nutrition across India and Bangladesh.

Thanks to initiatives like **HarvestPlus**, over **70 million people** in more than 40 countries are now consuming biofortified foods.

How Does It Work?

There are three main methods:

1. **Conventional Breeding** – Cross-breeding naturally nutrient-rich varieties with high-yielding ones.

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2. **Genetic Engineering** – Inserting specific genes to produce nutrients (e.g., Golden Rice for vitamin A).
3. **Agronomic Biofortification** – Applying micronutrient-rich fertilizers to boost mineral uptake.

Each method has its pros and challenges, but they all share the same goal: to make essential nutrition more accessible from the ground up.

Challenges Ahead

Despite its promise, biofortification still faces hurdles:

- **Consumer awareness**: Many people are unaware of the benefits of these crops.
- **Distribution**: Seeds must reach remote areas where they're needed most.
- **Policy support**: Governments must invest in research, education, and incentives.

Still, the momentum is growing. As food systems evolve to meet climate and health demands, biofortified crops offer a path toward a **healthier, hunger-free future** one meal at a time.

The Bottom Line

Biofortification isn't just science it's smart farming for better health. By enriching the world's most common crops with vital nutrients, we're not only feeding the world, we're nourishing it.

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Rhizosphere Engineering: Unlocking the Next Frontier in Crop Productivity

Jeyajothi. R[1], Akshaya S. B[2] Shakila Sadasivam[3], Akino Asokan[4] and Vinothini. N[5]

[1]Department of Agronomy,[2]Department of Plant Pathology, [3]Department of Fruit Science,
[4]Department of Floriculture and Landscape Architecture, [5]Depatment of Seed Science and Technology

SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu, Tamil Nadu – 603 301, India.

Introduction

The rhizosphere is a dynamic soil region influenced by root secretions (exudates) and microbial activity, where intense nutrient exchange occurs between plant roots, soil particles, and microorganisms. The plant rhizosphere is regarded as a microbial hotspot due to a wide array of root exudates. These root exudates comprise diverse organic compounds such as phenolic, polysaccharides, flavonoids, fatty acids, and amino acids that showed chemotactic responses towards microbial communities. The rhizosphere is considered the most intricate microbial environment. Interactions between plants and microbes and various processes in the rhizosphere are vital for improving plant resilience to environmental disturbances

Engineering Mechanisms

Rhizosphere engineering is achieved through three essential mechanisms: a) plant-mediated modifications involving genetic engineering, transgenics, and gene editing of plants; b) microbe-mediated modifications involving genetic alterations of microbes through upstream or downstream methodologies AgriVoltaics World Conference | AgriVoltaics World Conference. These approaches allow scientists to precisely control and optimize the microbial communities that colonize plant roots.

Plant-Microbe Communication

Plants develop complex interactions and communicate with various microbes in their rhizosphere through different signals that affect plant growth and modulate the plant-specific core root microbiome.

Applications in Sustainable Agriculture

Plant Growth Promotion: The rhizosphere microbiome plays a critical role in plant health and productivity by fostering beneficial microbial interactions that support nutrient cycling, stress tolerance, and disease suppression Global phosphorus shortage will be aggravated by soil erosion |Nature Communications. PGPB may play an additional role and environmental conditions, support the plant development, growth, health and nutrition and enhance its ability to resist biotic and abiotic stresses, such as soils with water or salinity deficiencies.

Climate Change Adaptation: The increasing impacts of global climate change on crop performance pose a significant threat to global food security. The rhizosphere microbiomes intimately interact with the plant and can largely facilitate plants in growth promotion and stress resistance via multiple mechanisms.

Genome-Microbiome Integration: The plant genome and its microbiome act together to enhance survival and promote host growth under various stresses. Plant microbiome plays an important role in plant productivity via a multitude of mechanisms including provision of nutrients and resistance against different biotic and abiotic stress.

Microbiome Manipulation Strategies

The rhizosphere microbiome plays critical roles in plant growth and provides promising solutions for sustainable agriculture. on stabilizing beneficial microbial communities and enhancing their functional capabilities.

Root microbiome is a significant driver for plant yield, health, and ecosystem functioning because it is the intersection point between a plant and the ecosphere. Furthermore, it is accountable for key functions such as nutrient acquisition and signals vital to plant development.

Recent research emphasizes the importance of understanding the connectivity between plant genes and rhizosphere microbiomes as a pathway for sustainable increases in primary productivity. The field is moving toward more precise manipulation of microbial communities, with applications ranging from enhancing nutrient uptake efficiency to developing crops with improved stress tolerance.

Rhizosphere engineering represents a paradigm shift from traditional agricultural practices toward biological solutions that harness the power of naturally occurring plant-microbe interactions while reducing dependence on synthetic inputs. This approach holds significant promise for addressing global food security challenges while promoting environmental sustainability.

Importance of Rhizosphere Engineering

- Boosts **sustainable agriculture** with less dependence on chemical inputs.
- Restores **soil biodiversity and health**.
- Supports **climate-smart farming** by increasing carbon sequestration and reducing emissions.

Microbiome Manipulation

- Introduction or promotion of **beneficial microbes** viz.,
  - **Rhizobacteria (PGPR)** – enhance root growth and nutrient uptake.
  - **Mycorrhizal fungi** – improve phosphorus and water absorption.
  - **Nitrogen-fixing bacteria** – support biological nitrogen fixation in legumes.
- Use of synthetic microbial communities (SynComs**)** tailored to crops.

Root Exudate Engineering

- Modifying root exudation patterns (sugars, organic acids, amino acids) to:
  - Attract beneficial microbes.
  - Mobilize nutrients (like phosphorus and iron).
  - Suppress soil-borne pathogens.

3. Soil Amendment and Conditioning

- Use of biochar, compost, or organic matter **to** improve rhizosphere structure and nutrient cycling**.**
- Adding nanoparticles **or** controlled-release fertilizers **t**hat interact specifically with the rhizosphere.

4. Plant Breeding and Genetic Engineering

- Developing crop varieties with:
  - **Efficient root systems** (architecture and depth).
  - **Enhanced root exudation** to recruit beneficial microbes.

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- **Stress-responsive rhizosphere interactions** (e.g., drought, salinity).

5. Water and Nutrient Efficiency

- Enhancing nutrient use efficiency (NUE) by engineering rhizosphere interactions.
- Improving water retention and uptake through hydrogel **or** soil microbiome-based solutions**.**

6.Pest and Disease Suppression

- Promoting rhizosphere microbes that:
  - Induce systemic resistance in plants.
  - Compete with or suppress pathogens like *Fusarium*, *Rhizoctonia*, or nematodes.
- Use of biocontrol agents (e.g., *Trichoderma*, *Pseudomonas*).

Importance of Rhizosphere Engineering

- Boosts **sustainable agriculture** with less dependence on chemical inputs.
- Restores **soil biodiversity and health**.
- Supports **climate-smart farming** by increasing carbon sequestration and reducing emissions.

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Arecanut and Its By-products: Unlocking the Potential of Nature's Multipurpose Palm

Varshini, N. V.[1], Vanathi, T.[2] and Bhoomika, H.R.[3]
[1]Young professional, Department of PSMAC, College of Horticulture Mudigere-577132
[2]Senior Msc., Department of PSMAC, College of Horticulture Mudigere-577132
[3]Scientist (Hort) ICAR- Krishi Vigyan kendra, Bramhavara, Udupi-576213
Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka

Introduction

Arecanut, botanically known as *Areca catechu*, is a tropical palm species from the Arecaceae family, widely cultivated across Southeast Asia. Commonly referred to as betel nut or *supari* in India, it is a significant commercial plantation crop. The fruit features a fibrous mesocarp, and its seed has a truncate base with a deeply ruminated endosperm and a basal embryo. The betel nut, which is the kernel extracted from the arecanut fruit, is widely used as a masticatory. In India, it holds cultural and religious significance and is an essential element in many rituals and ceremonies. Traditionally, a betel nut is placed on a ceremonial plate as it is believed to bring prosperity. It is also customarily offered to guests along with a betel leaf as a gesture of respect. Additionally, the nut finds use in indigenous medicinal practices for both humans and animals.

India is the leading producer and consumer of arecanut globally, accounting for approximately 58% of the total cultivation area and 53% of global production. In the year 2013–14, the country's arecanut production surpassed 700,000 tonnes. According to revised estimates for that year, the area under arecanut cultivation was around 445,000 hectares, with a total production of 729,810 tonnes. Annual domestic consumption is estimated at around 330,000 tonnes. It is believed that over 10 million people in India depend on arecanut cultivation and related activities for their livelihood. Arecanut is a

major plantation crop in the coastal and southern districts of the country, particularly in regions with assured irrigation. Karnataka stands as the largest arecanut-producing state in India.

Arecanut is available in various forms in the market, such as powder, gutkha, pan masala, and scented varieties. Additionally, tannin extracted from arecanut can also be utilized in the production of several other products.

Arecanut by products and its uses

Tannin (Chogaru):

It is obtained while kalipak preparation it is called kali or chogaru The sediments found in the tannin when it is dried, is called areca nut dust. Tannin in areca nut were being used for dyeing clothes and tanning leather. It can be used as an adhesive in ply board manufacture. Another possible use of areca tannin is as a safe food coloring agent. Black writing ink of acceptable quality may be prepared. Further, it is also useful in protecting house hold furniture by applying it like varnish. In the olden days tannin is used like paints to color walls. Traders use it to store areca for long duration by applying it. So that, necessary research may be undertaken to prepare acceptable wood oil and gums by using tannin as a major ingredient. Department of Chemistry of Delhi University and Chemical Technology, University of Bombay had undertaken study to identify the properties of tannin to find out to its alternative uses.

Areca Fat and its uses:

The areca nut contains 8-12 percent fatness. It can be extended by solvent extraction using hexane. It can be made edible by refining it using soda lime'. The refined areca fat is harder than cocoa, butter and even better, due to its high muriatic acid content. It could be softened by undergoing certain chemical processing and then it can be used as confectionery fat. Simple mixture of areca fat with butter fat at 3:1 ratio or with cocoa fat at 1:1 ratio could give product acceptable in confectioneries. Further, it could be used in preparation of biscuits, soaps, tea, chocolates, rasam powder, pickle, wine, herbal powder, cool drinks, syrup, gum, sweets, vinegar and savories and in place of vanaspati. Encouraging result have been obtained in preparing chewing gum and tooth paste using this extract of areca nut. Sweet supari making requires variety without fat.

Arecanut husk and its utility

Areca husk, also known as betel nut husk, is a by-product of the betel nut industry. Betel nut is a popular stimulant consumed by millions of people in Southeast Asia, India, and other parts of the world. The betel nut is wrapped in a leaf along with other ingredients like lime and spices and then chewed. Areca husk is the outer covering of the betel nut, which is removed before the nut is consumed. In recent years, there has been increasing interest in the potential uses of areca husk. Research has shown that it contains various bioactive compounds such as alkaloids, flavonoids, and tannins, which have potential applications in medicine and industry. One of the most promising uses of areca husk is as a source of bioactive compounds for the pharmaceutical industry. Studies have shown that some of the alkaloids found in areca husk have anti-cancer, anti-inflammatory, and anti-microbial properties. These compounds could be used to develop new drugs to treat a range of diseases. In addition to its potential medicinal uses, areca husk also has applications in industry. The tannins found in areca husk have been shown to have properties that make them useful in the production of adhesives, dyes, and leather. Areca husk could also be used as a biofuel, as it contains a high level of cellulose, which can be converted into energy. The outer fibrous covering of the areca nut, known as the husk, is often discarded as waste. However, the husk can be used as a source of biofuel. Areca husk has a high calorific value and can be burned to generate heat or

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electricity. It can also be converted into bio char, which is a type of charcoal that can be used as a soil amendment to improve soil fertility and reduce greenhouse gas emissions.

Sawdust

Sawdust is a byproduct of wood processing, created when wood is sawn or planed into lumber. It is a fine, powdery material that is produced in large quantities in sawmills and woodworking shops. Sawdust is composed mainly of cellulose, hemicellulose, and lignin, which are the major components of wood. Sawdust has many uses and applications. It is commonly used as a fuel for heating and cooking, as it is a low-cost and readily available biomass fuel. Sawdust can also be used in the production of particleboard, a composite material that is made by binding together small wood particles with resin. In addition, sawdust can be used as a soil amendment, as it is rich in organic matter and can help to improve soil structure and fertility. Sawdust is also a valuable raw material for the production of biofuels and other bioproducts. It can be converted into biochar, a type of charcoal that is used as a soil amendment and for carbon sequestration. Sawdust can also be processed into bio-oil, a liquid fuel that can be used as a substitute for diesel or gasoline.

Areca nut Husk Fiber

Areca nut husk fiber is a natural fiber that is obtained from the husk of the areca nut. Areca nut is a fruit that is commonly found in South and Southeast Asia. The husk of the areca nut is usually discarded as waste after the nut is harvested. However, the husk contains a fibrous material that can be processed into a useful fiber. Areca nut husk fiber is a versatile material that can be used in a variety of applications. It has high tensile strength and is resistant to abrasion, making it

suitable for use in textiles and ropes. The fiber is also biodegradable and eco-friendly, making it a sustainable alternative to synthetic fibers. In addition to its use in textiles and ropes, areca nut husk fiber is also used in the production of various handicrafts and home decor items. It can be woven into mats, baskets, and other decorative items. The fiber is also used in the production of paper and packaging materials.

Conclusion

The arecanut plant is not only culturally significant but also economically and industrially valuable. Its various by-product tannin, fats, husk, and fiber offer diverse applications in fields like food, pharmaceuticals, textiles, and renewable energy. Utilizing these by-products promotes sustainability and reduces agricultural waste. With continued research and innovation, arecanut can significantly contribute to eco-friendly development and rural livelihoods.

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Technology's Role in Achieving Intragenerational and Intergenerational Equity in Indian Agriculture

K Archana[1*], C Lokesh[2], Sravani Arem[3], L Harika[4]

[1,4] MSc Agronomy (Water Management), Professor Jayashankar Telangana Agricultural University.

[2,3] PhD. Agronomy, Professor Jayashankar Telangana Agricultural university.

Agriculture is vital for India's economy and food security, especially with a population of over 1.4 billion. Technology plays a crucial role in addressing the dual challenge of **intragenerational equity**—feeding the current population—and **intergenerational equity**—preserving resources for future generations. By improving productivity and promoting equitable resource distribution, technology supports Sustainable Development Goals (SDG) 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production). Although agriculture employs 42.3% of India's workforce, it contributes only 18.2% to GDP, highlighting the need for technological advancements to boost efficiency and ensure sustainable development for present and future generations.

As M.S. Swaminathan, the Father of the Green Revolution in India, aptly stated: ***"The future of Indian agriculture depends not only on how we grow food today but also on how we use technology to ensure that both present and future generations can thrive."*** This quote underscores the importance of balancing current agricultural productivity with the sustainability needed for future generations.

Intragenerational equity ensures fair distribution of resources and technological innovations among all farmers within the current generation, promoting balanced agricultural development. **Intergenerational equity**, on the other hand, emphasizes the responsibility of the present generation to use resources sustainably, preserving agricultural potential for the future. Both concepts are essential for achieving a productive and equitable agricultural sector today while safeguarding the environment and resources for future generations.

Technological Innovations Driving Intragenerational Equity

For intragenerational equity, several technological innovations are making significant strides in leveling the playing field for farmers across different socioeconomic backgrounds. Digital tools, such as mobile apps and platforms providing real-time information on weather patterns, soil health, and market prices, are empowering smallholder farmers to make informed decisions. These tools, combined with precision farming techniques that optimize resource use—such as GPS-guided equipment and sensor-based irrigation—allow even resource-poor

farmers to increase their productivity and reduce waste. By making advanced agricultural technologies more accessible and affordable, these innovations help reduce the disparities between large and small-scale farmers, ensuring that all farmers can benefit from technological progress.

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Technological Innovations Driving Intergenerational Equity

For intergenerational equity, the focus is on sustainable technological innovations that ensure the long-term viability of agriculture for future generations. Key innovations include sustainable agriculture practices such as conservation tillage, crop rotation, and integrated pest management (IPM), which maintain soil health and reduce environmental impact. Additionally, the development of climate-resilient crops through biotechnology is crucial, as these crops can withstand extreme weather conditions brought about by climate change. Renewable energy technologies, like solar-powered irrigation systems, also play a critical role by reducing agriculture's reliance on fossil fuels, thereby minimizing environmental degradation. These innovations ensure that the resources necessary for farming—such as fertile soil, clean water, and a stable climate—are preserved and even enhanced for the farmers of tomorrow.

Case Studies

The Green Revolution: A Double-Edged Sword

India's Green Revolution of the 1960s and 1970s was a double-edged sword, transforming the nation's agricultural landscape. Innovations like high-yield variety (HYV) seeds, chemical fertilizers, and advanced irrigation significantly boosted crop productivity, particularly in wheat and rice, pulling the country from famine to self-sufficiency. However, this success came with long-lasting consequences. Environmental degradation from overuse of chemical inputs, socioeconomic inequalities as smallholder farmers struggled with costs, and the reduction of agricultural biodiversity due to monoculture practices were key challenges. While the Green Revolution improved food security, it highlighted the risks of technological interventions without a long-term perspective on sustainability and equity.

Madhya Pradesh's Solar Pumps: A Step Towards Sustainable Agriculture

Madhya Pradesh's adoption of solar-powered irrigation pumps marks a significant step towards sustainable agriculture, offering consistent and reliable power for farmers. This initiative enhances agricultural productivity, reduces dependence on erratic power supplies, conserves energy, and provides environmental benefits. Additionally, it offers economic advantages by lowering farmers' operational costs and promotes long-term sustainability by integrating renewable energy. This approach not only addresses current agricultural challenges but also ensures future resource preservation, creating a more resilient and equitable agricultural system for generations to come.

Challenges

Integrating technology into Indian agriculture holds great promise but faces challenges like the **digital divide, financial barriers, and knowledge gaps**. Limited access to digital tools in rural areas, where most farmers reside, prevents them from leveraging technologies that could boost productivity and sustainability. Small and marginal farmers, who are crucial to India's agricultural sector, often lack the financial means to invest in costly technologies like precision farming. Additionally, many farmers are unaware of or untrained in modern tools, highlighting the need for stronger extension services. Policy and regulatory hurdles, such as delays in adopting GM crops, also hinder progress. Clear policies and farmer education are essential to ensuring technology benefits all, now and for future generations.

The Road Ahead: Recommendations for Policy and Practice

To fully harness the potential of technology in achieving intragenerational and intergenerational equity in Indian agriculture, several measures need to be taken:

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1. Strengthening Infrastructure
2. Subsidies and Incentives
3. Promoting Public-Private Partnerships
4. Enhancing Farmer Education and Training
5. Ensuring Sustainable Practices

Conclusion

The integration of technology in Indian agriculture holds the promise of achieving both intragenerational and intergenerational equity. By enabling more efficient, productive, and sustainable farming practices, technology can help ensure that the benefits of agricultural progress are shared equitably across different segments of society and passed on to future generations. However, realizing this potential requires concerted efforts to address the challenges of access, affordability, and awareness, ensuring that the fruits of technological advancements are available to all. Through strategic investments, supportive policies, and a focus on sustainability, India can pave the way for a more equitable and prosperous agricultural future.

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Improved Cultivation Practices of Cauliflower for Higher Yield

Dr. Manju Kumari
Subject Matter Specialist Horticulture, Krishi Vigyan Kendra, Kishanganj Bihar

Introduction

Cauliflower (*Brassica oleracea* var. *botrytis*) is a highly valuable and most extensively grown winter crop in India. It is a member of the family Brassicaceae and is cultivated mostly for its tender and edible white curd, which is actually a proliferated inflorescence. Cauliflower is well known for its nutritional value being a good source of vitamins C and K, folate, dietary fiber, and many phytochemicals that possess antioxidant and anti-inflammatory activities. These qualities position it not only as an Indian staple, but also as a healthy choice for health-oriented consumers.

Because of its flexibility under a variety of agro-climatic conditions, cauliflower is grown in nearly all Indian states, the top production centers being in Uttar Pradesh, West Bengal, Bihar, Maharashtra, and Gujarat. Cauliflower is produced in various seasons early, mid, and late with the culture of varied varieties and hybrids available for each growing period.

Economically, cauliflower production is also very lucrative and constitutes a sure source of income for marginal and small farmers. Due to relatively short duration of the crop, high land use efficiency, and high market demand in urban and rural markets, it will also integrate well into various multiple cropping patterns. Moreover, value addition through processing (such as pickling, dehydration, frozen curd) and its incorporation into agri-export chains also boosts its commerciality.

Therefore, with optimal agronomic practices, integrated pest and nutrient management, and post-harvest management, the cultivation of cauliflower has great potential to enhance farmer incomes and contribute to nutritional security in India.

Climatic and Soil Requirements

Climate

Cauliflower is chiefly a cool-season crop that performs best under moderate climatic conditions. The ideal temperature for the development of curd varies from 15°C to 20°C. Yet, cauliflower varieties suitable for varying climatic conditions, ranging from early to late-maturing types, have been developed. Temperature extremes either too low (lower than 10°C) or too high (higher than 25°C) will negatively impact curd formation, producing defects such as buttoning, riceyness, or loose curds. A cool and damp climate during curd formation improves yield and quality. Early-season types withstand fairly warmer temperatures, whereas late-season varieties need clearly cooler environments.

Photoperiod also affects the development and growth of cauliflower. Increased days can support vegetative growth, while shorter day lengths that occur in cooler months are best for reproductive development, particularly curd formation.

Soil

Cauliflower grows well in fertile, well-drained loamy soils that contain plenty of organic matter. The suitable pH of the soil is between 6.0 and 7.0. Soils having good water-holding capacity without waterlogging are desirable, as waterlogged conditions cause root rot and other physiological disorders. Sandy loam soils are suitable for early crops because of improved drainage and faster warming of the soil, while clay loams are suitable for main-season crops since they hold water longer.

For uniform curd development, the soil must be friable, well-tilled, and free from hard pans which may hinder root growth. Land preparation with the

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inclusion of well-decomposed farmyard manure or compost (at least 20–25 tons/ha) improves soil texture and fertility.

Altitude

Cauliflower is successfully cultivated from plains to hill areas and is therefore a highly adaptable crop. Early and mid-season crops are grown in plains during Rabi season, whereas in hills, it is grown during summer seasons when the temperature is favorable for maximum growth. The crop grows well at altitudes of sea level to 2000 meters mean sea level (MSL), given that climatic conditions are suitable as per varietal needs.

Varieties of Cauliflower

Selecting the right variety based on the sowing season and regional climate is crucial for successful cauliflower cultivation. Cauliflower varieties are broadly categorized into early, mid, and late groups, depending on their sowing and harvesting times, as well as their temperature requirements for curd formation.

- ✓ **Early Group**: Pusa Early Synthetic, Pant Gobhi-2, Early Kunwari
- ✓ **Mid Group**: Pusa Shubhra, Pusa Snowball K-1, Pusa Himjyoti
- ✓ **Late Group**: Pusa Snowball-16, Improved Japanese, Snowball-25

Land Preparation

Good land preparation is an important process in successful cauliflower production, as it provides for good establishment of seedlings, root penetration, and even growth. The objective is to obtain a fine, friable, and well-aerated tilth soil that promotes root growth._and water retention, as well as allowing proper nutrient uptake.

Primary Tillage

Begin with 2–3 churning ploughings with a mouldboard or disc plough to shatter hardened layers and bring in crop residues. Every ploughing must be followed by harrowing to crush clods and level the land. A fine tilth is particularly desirable for cauliflower, as it aids the establishment of an even root system and good curd development.

Incorporation of Organic Matter

At the final ploughing, use and well incorporate 20–25 tons per hectare of well-decomposed farmyard manure (FYM) or compost into the soil. This organic matter enriches soil structure, increases microbial activity, increases nutrient availability, and enhances water-holding capacity especially where soil is light.

Besides FYM, green manuring using crops such as dhaincha or sunnhemp can be done during the off-season to further supplement the soil with organic matter and nitrogen.

Leveling and Bed Formation

Once ploughing and manuring are complete, the field needs to be leveled adequately for even irrigation and drainage. According to season and crop variety, form ridges and furrows, raised beds, or flat beds. Raised beds are particularly apt for waterlogged areas.

Drainage

Cauliflower is water-sensitized and has a strong tendency to develop root diseases and poor plant growth due to too much water and waterlogging. Ensure that there is proper drainage channels or a slight slope in the field to promote easy movement of water and avoid stagnation, especially during heavy rains.

A well-prepared field not only promotes seedling establishment and minimizes competition from weeds but also establishes the groundwork for even curd development and greater marketable yield.

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Sowing Time (Northern India)

Group	Nursery Sowing	Transplanting	Harvesting
Early	May–June	June–July	August–September
Mid	July–August	August–September	October–November
Late	September	October	December–January

Irrigation

Timely and efficient irrigation is important for cauliflower growth, high yields, and proper curd formation. The crop has a shallow root system, making it vulnerable to water stress as well as waterlogging, and hence requires cautious irrigation planning.

First Irrigation

The initial irrigation must be provided immediately after transplanting to settle the soil around the roots and to alleviate transplanting shock. Light irrigation is best to prevent displacement of the roots or erosion of young seedlings.

Subsequent Irrigations

Cauliflower needs frequent irrigation at 7 to 10 day intervals based on soil type, weather, and crop growth stage. Sandy soil requires more frequent irrigation, but clayey soils have better water-holding capacity and, therefore, require less frequent irrigation. Adequate soil moisture during the vegetative phase ensures the development of healthy leaves and stems that will support the curd later.

Critical Stage – Curd Formation

The most essential phase for irrigation is in curd formation and development. Any moisture stress at this phase can lead to suboptimal curd formation, discolouration, decreased size, and even deformation (e.g., riceyness or leafiness). Therefore, provide uniform and optimal moisture in the root zone at this stage to achieve compact, white, and saleable curds.

Waterlogging and Drainage

Though moisture is necessary, waterlogging must be avoided at all costs as it will lead to rotting of roots, damping-off, and support fungal infections. Raised beds or ridges and furrows are the suggestions in regions where too much rainfall is expected to avoid stagnation.

Irrigation Techniques

Furrow irrigation is usually followed in traditional fields.

Under precision farming or in water-deficient regions, drip irrigation can be used to supply uniform moisture, conserve water, and allow for fertigation. Mulching with organic residues such as straw, dry leaves, or plastic mulch can conserve water, control soil temperature, and decrease irrigation frequency. Optimum irrigation scheduling not only maximizes the quality and yield of the curd but also enhances water-use efficiency, thus a more sustainable cultivation.

Spacing

There should be proper spacing in cauliflower cropping to provide proper sunlight interception, air flow, and nutrient supply. It also reduces the occurrence of diseases and makes intercultural activities such as weeding and spraying easier.

Early Types: These tend to be smaller and have an early maturing period. Spacing at 45 × 45 cm (plant to plant and row to row) is optimum for early-maturing types so as to have maximum plant population without congestion.

Mid and Late Varieties: These varieties are more vigorous in growth and need more space. More spacing of 60 × 60 cm is advocated to provide room for their bigger canopy and better curd formation. Space slightly according to soil fertility and growth

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habit of the variety. For intensive cultivation systems, closer spacing can be employed for high-density plantation in early types.

Nutrient Management

Well-timed and balanced fertilizer application is essential to promote vigorous vegetative growth, favorable curd formation, and high marketable yield in cauliflower. Organic and inorganic sources of nutrients must be incorporated to maintain sustainable soil fertility and enhance crop response.

Basal Dose (per hectare)

Farmyard Manure (FYM): Incorporate 20–25 tons of well-decomposed FYM at land preparation to raise the level of soil structure, microbial activity, and long-term fertility. Chemical Fertilizers (NPK): 125 kg Nitrogen (N), 75 kg Phosphorus (P_2O_5), and 60 kg Potassium (K_2O) per hectare. Phosphorus and Potassium full dose must be applied basally during final land preparation. 25% of the total Nitrogen is also applied as basal along with P and K.

Harvesting & Yield

Cauliflower harvesting is a critical stage that directly impacts the quality, shelf life, and market value of the produce. Timely harvest ensures optimal curd size, texture, and appearance.

Harvesting Time: The curds must be harvested while they are dense, well-developed, white, and hard to the touch, but before they start loosening or developing signs of discoloration. They do this 80–120 days after planting, depending on season and variety.

Delayed harvesting makes curds loose, ricey, or yellow, lowering their market acceptability and resulting in economic loss.

Harvesting can be done preferably during early morning or late evening to prevent heat-induced wilting. Use a sharp knife to cut the curd, leaving some wrapper leaves intact to cover the curd while in handling and transport.

Yield: Average yield of cauliflower depends on the variety, time of year, and management practices:

Early types: 15–20 tons/ha

Mid and late types: 25–30 tons/ha or more with good management. With hybrids and better practices, yield can be more than 35 tons/ha

Major Pests & Diseases

Pest/Disease	Control Measures
Cabbage butterfly	Spray Malathion 0.1%
Aphids	Dimethoate 0.05% or neem extract
Damping off	Treat seed with Captan @ 2 g/kg seed
Black rot	Use disease-free seed, crop rotation
Downy mildew	Spray Metalaxyl + Mancozeb

Marketing & Value Addition

Post-harvest handling, grading, and marketing can contribute tremendously to profitability for cauliflower farmers.

Grading and Packing: After harvesting, curds must be graded according to size, color, and compactness. Well-graded curds are sold at better prices. Pack them in plastic crates, bamboo baskets, or jute bags with protective leaves to prevent mechanical damage during transit.

Transportation: Because the curd is firm and compact, cauliflower is suitable for long-distance transportation. Quick transport to the market, however, is recommended to preserve freshness and prevent spoilage.

Storage: Cauliflower may be stored at 0–1°C with relative humidity of 90–95% for 2–3 weeks. Promoted marketing under ambient conditions can decrease quality markedly.

Value Addition Opportunities

- ✓ Freezing and dehydration for export or urban retail chains
- ✓ Pickling and curd-based mixed vegetable processing
- ✓ Market opportunity for ready-to-cook and pre-cut packaging in urban markets

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Crop Price Forecast & Market Linkages: Enhancing Farmer Income and Market Efficiency

Rita Fredericks
CEO, Precision Grow (A Unit of Tech Visit IT Pvt Ltd)

Introduction

Crop price prediction and forecasting market linkages are essential elements of a contemporary agricultural economy. Small farmers in India tend to suffer from unanticipated prices and restricted market access, resulting in income uncertainty and distress selling. Reliable price forecasting enables farmers to take informed decisions on crop production and selling, while well-functioning market linkages ensure higher price realization and minimized reliance on intermediaries. By combining technology, institutional support, and policy changes, these tools have the potential to greatly boost farm profitability, empower rural communities, and strengthen a more transparent, efficient, and resilient agri-market ecosystem.

1.1 Background

Indian agriculture and that of most developing nations is primarily controlled by small and marginal farmers who rely on conventional market systems to market their produce. Agricultural markets in such areas are, however, beset by price fluctuations, disorganized supply chains, inferior infrastructure, and absence of timely market information. Farmers have no option but to sell their produce at the time of harvest as they run out of storage or hardly receive low prices in the market. The result is distress sale, poor price recovery, and ultimately reduced income. Adding to this malady is the absence of access to adequate and timely market information. Most farmers do not know current market trends and cannot schedule production depending on future demand and price signals. Birthal *et.al.* 2007. Consequently, most crops are either overproduced or underproduced, resulting in either gluts or shortages in the market. Such inefficiency not only impacts farm incomes but food security and the agri-economy as a whole.

1.2 Crop Price Forecasting Need

Crop price predictions are an important decision-support tool for farmers to make strategic decisions regarding crop choice, sowing and harvesting timing, and post-harvest handling. A consistent prediction supports the estimation of future price patterns based on supply-demand conditions, weather forecasts, government regulations, and past price data.

- Decision-making: Farmers are able to select crops that are likely to command higher prices in the next season, thus improving profitability.
- Risk management: Reliable price projections reduce the risks of price collapses, and farmers can either store crops or sequence their sales in time accordingly.
- More effective resource allocation: Projections assist farmers in allocating land, labor, and inputs more optimally, and can lead farmers to diversify crops on the basis of predicted market response.

Source: https://www.mdpi.com

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1.3 Role of Market Linkages

Market linkages are instrumental in changing agriculture from production-oriented to market-oriented agriculture. By establishing strong and secure links between markets and farmers, they enable farmers to receive reasonable prices and eliminate exploitation by intermediaries.

Improved price realization: Direct marketing channels like FPOs, contract farming, and e-markets help farmers reach the buyers offering competitive prices.

Reduced dependency on middlemen: By bypassing traditional layers of commission agents and traders, farmers retain a greater share of consumer prices.

Increased transparency and bargaining power: Strong market linkages empower farmers to negotiate better terms, ensure quality assurance, and access timely payments.

2. Methods of Crop Price Forecasting

Precise forecasting of crop prices is needed for reducing market uncertainty and enabling timely, profitable decisions by farmers. Statistical models to advanced artificial intelligence techniques are employed these days to forecast future prices considering several influencing parameters.

2.1 Statistical Models

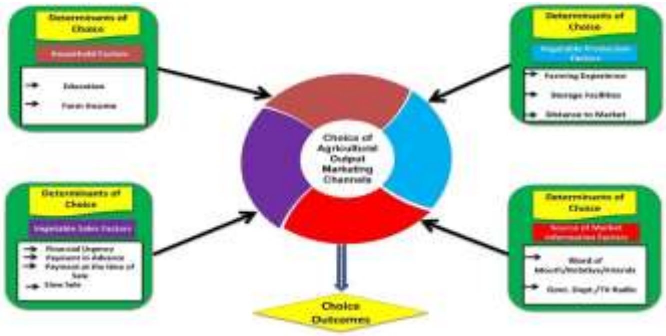
Statistical models have been the mainstay of agricultural price predictions. Such models use past price observations and related variables such as rainfall, cultivated area, and demand forecasts.

Time Series Models:

Statistical methods such as ARIMA (AutoRegressive Integrated Moving Average) and Exponential Smoothing examine historical patterns in prices over a time dimension in order to forecast future values. They work best when prices move in seasonal or cyclical trends, as happens frequently with agricultural commodities.

Regression Models:

Regression analysis investigates the interaction between crop prices and drivers like supply quantity, rainfall, fertilizer supply, or demand pattern. Multiple regression models permit multiple variables to be included, ensuring the projections are accurate under varied conditions.



Source: https://www.frontiersin.org

2.2 Machine Learning and AI Models

Recent developments in artificial intelligence (AI) and machine learning (ML) have made crop price forecasting systems much more accurate and responsive. Large, intricate datasets can be processed and non-linear relationships can be learned by these models that conventional models can miss. Random Forests, Support Vector Machines (SVMs), and Artificial Neural Networks (ANNs) are widely employed to predict prices by examining patterns within data such as crop acreage, climatic anomalies, market arrivals, and export-import patterns. Haji *et.al.* 2008. Such models typically integrate real-time information like weather conditions, satellite images, and sentiment analysis from the news or social media into their model, providing dynamic and localized forecasting facilities.

2.3 Official Government and Institutional Forecasts

Multiple government institutions are of critical importance in making forecast data available:

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- Agmarknet and Directorate of Economics & Statistics (DES) offer mandi-level historical and real-time crop price and arrival data.
- State Agricultural Universities (SAUs), in association with the Ministry of Agriculture, and institutions such as IIMs, create region-specific price predictions. These tools are usually made available through agricultural extension agencies, the press, and radio.

2.4 Market Intelligence Tools

Online platforms and tools have made access to price prediction data much easier:

- Mobile Advisory Apps: eNAM, Kisan Suvidha, and AgriApp are some of the tools that provide current market prices, future price expectations, and selling advice to farmers.
- ICT-based Tools: Organizations such as ICAR, IFFCO, and KVKs use SMS alerts, community radio, and rural knowledge centers to distribute price and market trend information to even the remotest farmers.

3.Market Linkage Models

Strong market linkages are important for empowering farmers, decreasing middleman dependence, and improving price realization. Strengthening the linkages helps farmers get access to wider markets, fair prices, and enhanced overall profitability. Different models of market linkage have cropped up over the last few years, each with some inherent strength and suitability. Saxena *et.al.* 2019.

3.1 Direct Marketing

Direct marketing enables farmers to sell produce directly to end-consumers without the involvement of intermediaries. The model provides improved prices to farmers and reduced prices to consumers. Good examples are Apni Mandis in Punjab and Haryana and Rythu Bazaars in Andhra Pradesh and Telangana. The farmer-run markets lower transaction costs and offer a platform for fresh local produce and foster trust among producers and consumers.

3.2 Contract Farming

Contract farming is a contractual arrangement between farmers and agribusiness companies where the purchaser agrees to take a given quantity and quality of produce at a predetermined price. In exchange, the firm might supply seeds, inputs, technical guidance, and market guarantee. This structure minimizes market risks for farmers while guaranteeing quality produce for companies. It is particularly applicable in high-value crops such as vegetables, fruits, and export crops.

3.3 Farmer Producer Organizations (FPOs)

FPOs are collective organizations established by aggregations of farmers with an aim to improve their bargaining power and marketing capability. By aggregating the produce, FPOs facilitate bulk sales, improved price negotiation, and access to input subsidies, credit, and godown facilities. They facilitate quality control, minimize wastage, and enhance supply chain efficiency. Govt. programs such as the SFAC and NABARD-backed FPOs have been crucial in scaling up this model.

3.4 e-NAM (National Agriculture Market)

e-NAM is a pan-India electronic trading platform that combines APMC markets within states to develop a common national market for agricultural commodities. It allows farmers to receive competitive prices through transparent bidding, real-time price discovery, and interstate trade. With online payments and electronic weighbridges, e-NAM empowers farmers and provides fair and transparent transactions.

4. Case Studies and Success Stories

The direct benefit of crop price prediction and market connections can be seen from several successful interventions in India. These actual case studies provide evidence of how farmers, once enabled with prompt information and market linkage, are able to increase income substantially and mitigate risk. Zulauf, et.al. 1998.

4.1 Price Forecast Adoption in Karnataka

The University of Agricultural Sciences (UAS), Dharwad introduced a pre-season forecasting scheme for tur (pigeon pea) and onion, two major crops of the state. Based on historical data, climatic trends, and market arrivals, the university made pre-season predictions through Krishi Vigyan Kendras (KVKs), print media, and farmers' meetings. Farmers reacted by modifying their sowing choices and changing harvesting schedules, particularly for onion, which is extremely price-responsive. Farmers also chose to temporarily store their produce, holding out for better prices rather than selling immediately after harvesting. This evidence-based method returned an additional 15–20%, proving the real value of decision-making based on forecast.

4.2 Market Linkage through FPOs in Maharashtra

In Nashik, Maharashtra, onion-farming farmers established a Farmer Producer Organization (FPO) that developed direct market connections with large retailers such as Reliance Fresh and Big Basket. With assistance from government agencies and local NGOs, the FPO improved post-harvest handling, quality sorting, and bulk packaging.Through these enhanced practices and direct deal-making, the FPO kept the intermediaries' role to a minimum, minimized post-harvest losses, and facilitated timely payment to members. The collective effort attained a 25% boost in average farmer income, and it was a replicable model in other perishable commodity regions.

4.3 ICT Tools in Madhya Pradesh and Telangana

In the hinterland villages of Madhya Pradesh and Telangana, digital media such as SMS messages and mobile apps were employed to communicate mandi prices for each day and trend estimates. Efforts initiated by Krishi Vigyan Kendras and agri-start-ups offered location-specific advisory services, enabling farmers to monitor market developments in real time.Through receiving notifications on market gluts or beneficial pricing days, farmers were in a position to stage their sales, diversify planting crops, and prevent distress selling. ICT tools efficiently minimized the negative effects of price volatility, particularly for small farmers, and promoted an educated farming community.

5. Challenges and Opportunities

The possibilities for crop price forecasting and enhanced market linkages to change Indian agriculture are huge. Nevertheless, turning this potential into reality needs overcoming numerous structural, technological, and institutional bottlenecks. Meanwhile, emerging technologies and changing policy support offer a variety of options for making agri-marketing more efficient, inclusive, and farmer-centric.

5.1 Challenges

Even with progress, farmers still encounter major hurdles:

Lack of good infrastructure for storage and transportation

Most of the post-harvest losses in India are caused by the absence of cold storage, warehouses, and efficient logistics. In the absence of storage, farmers end up selling at harvest time when prices are low, rendering price forecasting useless.

Limited Digital Literacy Among Farmers

Most smallholder farmers are not aware of digital platforms and tools that provide price updates, forecasts, or market access. Slow smartphone penetration, limited internet connection in rural areas, and lack of training constrain the use of ICT and mobile-based solutions.

Delay in Data Availability and Forecast Accuracy:

The accuracy and timeliness of price predictions rely on up-to-date information, which is sometimes delayed or unreliable owing to data collection gaps, aggregation, and dissemination. This compromises the reliability of predictions and can cause suboptimal decisions.

Inefficiency in APMC Markets and Middlemen Control

Traditional Agricultural Produce Market Committees (APMCs) are highly intermediated. This leads to opaque prices, bid manipulation, and delayed payment to farmers, keeping them away from proper benefits of correct market information.

5.2 Opportunities

In spite of challenges, a range of emerging opportunities hold out the promise of systemic change:

FPOs and Warehouse Linkages:

Investment in Farmer Producer Organizations and their warehousing infrastructure access can facilitate pooled storage and staggered sale, helping improve income through improved price realization.

Encouraging Agri-Tech Startups for Real-Time Price Projections:

The emergence of data analytics, remote sensing, and AI-based startups offers a potential route for providing real-time, localized price projections and market intelligence.

Smart Contracts Based on Blockchain:

Smart contracts can enable secure, transparent, and tamper-proof exchanges between buyers and farmers, guaranteeing timely payments and equitable trade practices.

Online Marketplaces Linking Farmers with Urban Consumers:

Players like BigHaat, Ninjacart, and DeHaat are already connecting farmers with retailers and consumers directly, eliminating intermediaries and raising the farmers' contribution to the final price.

6. Recommendations and Way Forward

In order to make crop price forecasting and market linkage systems good tools for enhancing farmer returns and mitigating rural distress, a combined effort of policy, institutions, and ground-level implementation is required. The below recommendations serve as a guide to create a more robust, data-driven, and market-led agricultural ecosystem.

6.1 Policy Recommendations

Implement Price Forecasting Units at the District Level: Special cells manned by agri-economists, statisticians, and data analysts need to be established at district levels to compile and release crop price forecasts on the basis of prevailing local market conditions. These units could operate alongside KVKs and SAUs.

Promote Private Sector Involvement in Market Platforms: Offer incentives to agri-tech startups and private enterprises to invest in creating digital agri-marketplaces, data analytics tools, and forecasting models accessible to smallholder farmers.

Incorporate Weather, Production, and Price Data: A single, centralized data system that integrates real-time meteorological data, sowing patterns, yield projections, and past price trends can greatly improve the validity and utility of forecasts.

6.2. Institutional Support

Enhance KVKs' Role in Farmer Training: KVKs must organize periodic training courses for farmers in interpreting price projections, delineating cropping

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patterns in consequence, and utilizing digital market materials.

Engage State Agricultural Universities (SAUs): SAUs must create region-specific crop price forecast bulletins, release seasonal advisories, and co-ordinate with local mandis to cross-check and update their projections.

Enable NABARD and SFAC to Scale Up FPOs: Increase financial and technical assistance to Farmer Producer Organizations by NABARD and SFAC so that they can participate more significantly in collective marketing, storage, and dealing with large buyers.

6.3 Farmer-Centric Solutions

Encourage Crop Planning Based on Forecasts: Urge farmers to take advantage of seasonal forecasts and price projections to determine what to plant, when to harvest, and how to sell their produce optimally.

Increase Digital Literacy and Mobile App Usage: Implement training modules within extension programs and farmer schools to educate farmers about the use of market information apps and accessing mandi prices, forecasts, and networks of buyers.

Develop Village-Level Infrastructure: Invest in setting up decentralized storage, grading, and packaging facilities at village levels to minimize post-harvest losses and enhance the quality and price of produce in the market.

7. Conclusion

Efficient crop price prediction and strong market linkages are imperative in stabilizing farmers' revenues, minimizing post-harvest wastage, and enhancing farmers' decision-making capabilities. Combining data-driven instruments, policy renewal, and institutional frameworks can open the doors to an agri-marketing ecosystem that is resilient and lucrative.

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Eco polymers and Leafy Greens: A New era in Sustainable Agriculture

[1]A. Fahima Fathima and [2]M. Dhanalakshmi

[1]Department of Vegetable Science, Tamil Nadu Agricultural University, Coimbatore

[2]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore

In modern world, where climate concerns and food security are tightly intertwined, growing health, sustainable food has never been more important. Among the many innovations in agriculture, the innovation that's quiet yet makes powerful impact is the use of biodegradable soil conditioning polymers-especially in the cultivation of leafy vegetables like spinach, lettuce, coriander, amaranthus and fenugreek. These polymers are not just improving soil and crop quality, but also offer an eco-friendly substitute for chemical dependent farming which helps both the farmer and the planet.

Soil conditioning polymers

Soil conditioners are substances added to soil to enhance its physical properties. Their main purpose is to improve water retention, aeration and the availability of nutrients-all of which directly influence plant health. While conventional conditioners such as peat moss, synthetic hydrogels have been used, they often come with environmental defective, especially derived from petroleum or non-renewable resources. Hence biodegradable soil conditioning polymers could be a best alternative form of sustainable farming

Types of Biodegradable polymers

- **Starch based polymers**: It is derived from crops like corn or potato. They are water-retentive and easily decomposed by soil microbes
- **Cellulose and its derivates**: It naturally occurs in plant cell walls, these polymers improve soil structure and microbial activity.
- **Chitosan**: It is obtained from crustacean shells, chitosan condition soil as well it possess anti-fungal properties.
- **Alginates**: It is extracted from brown algae, alginates can hold water well and create gel-like matrices around the roots.

Agro products derived from biodegradable polymers

Mulch films:

Mulch film can be used for soil moisture conservation, soil temperature management, weed control, nutrient conservation, pest control and to improve yield. Mulch films are utilized in numerous cultivation practices including vegetable cultivation. It increases crop harvesting and quality in vegetable production by suppressing weeds, preserving soil hydration and controlling soil temperature. It also helps by stopping the leaching of pesticides and fertilizers into the earth. Biodegradable polymeric mulches have benefits over conventional mulches such as increased water absorption, decreased weed development and increased agricultural output most importantly no consumption of land-filling sites as they degrade on the soil without leaving any toxic residue in them. The polymers used for mulch films are Cellulose, Starch, Polylactic acid, Polybutylene succinate, Polycaprolactane, Polybutelene adipate terephthalate.

Seed coating

Seed coatings are another utilisation of biodegradable polymers in horticulture. The purpose

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of seed coating is to shield seedlings from insects, diseases and weather stressors. Non-bio degradable polymers could be replaced with bio degradable polymers. Bio degradable polymeric seed coverings provide a regulated discharge of nutrients, provide protection against pests and diseases and enhance soil's physical qualities. The polymers used for seed coating are Chitosan, Polylactic acid, Cellulose and Gelatin. Recently, a biopolymer mixture of starch, gelatin and polyvinyl alcohol have been used due to its good adherence to seeds. The bio degradable polymers are typically applied by seed-treating devices like rotating drum, rotary coating, fluidized bed, electrospinning that evenly cover the seeds.

Agrochemical delivery

Modern agricultural methods frequently employ agrochemicals such as fertilizers, pesticides, herbicides and growth regulators to increase crop yield and safeguard harvest from pests and diseases. The indiscriminate use of chemicals can harm the ecosystem and human health as well. Biodegradable polymers materials can substantiate conventional chemical delivery method. Several biodegradable polymers like polylactic acid, polyhydroxyalkanoates, starch-based polymers and cellulose based polymers can be used to control the distribution of pesticides, herbicides and plant nutrients depending on their biocompatibility, biodegradability and controlled release characteristics.

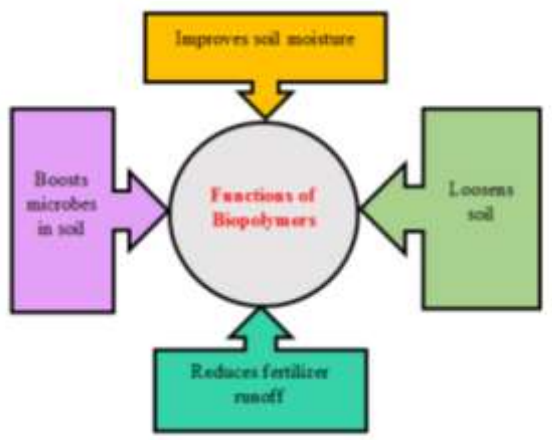
Role of bio degradable polymers in leafy vegetable cultivation

Leafy vegetables are among the most water-sensitive and nutrient demanding crops. Their shorter life cycle and shallow root systems make them vulnerable to change in soil moisture, nutrient availability and temperature. Inadequate irrigation or poor soil health often leads to

- Wilting and reduced crop biomass
- Premature bolting
- Lower nutritional quality
- Susceptibility to pests and diseases

Biodegradable polymers counteract these problems in leafy vegetables by

- Improving soil moisture: It acts like mini-reservoirs, they absorb water during irrigation or rain and release it slowly as plants need it.
- Loosening compact soil. It enhances aeration and drainage, supporting healthy root development.
- Boosting microbial activity. The breakdown product of bio degradable polymers feed beneficial microbes, improves nutrient cycling in the rhizosphere.
- Reducing fertilizer runoff: Nutrients released from bio degradable polymers are held longer in the root zone, increasing uptake and reducing waste.



A pictorial representation of biopolymer application in leafy vegetables

Field applications and benefits in practice

Case study 1: Spinach in sandy soils

In arid region with sandy soil spinach is hard to cultivate due to rapid water loss. When farmers

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incorporated starch based polymers at rate of 2.5% (w/w), they observed:

- 25-35 % increase in leaf biomass
- Reduced irrigation frequency by 40%
- Extended harvest window due to delayed wilting

Case study 2: Lettuce in urban gardens

Urban rooftop gardeners in India and Europe have successfully used alginate and cellulose based containers to grow lettuce. These gardens exhibited

- Uniform leaf growth
- Less fertilizer use
- Improved flavour and crispness (attributed to steady water supply)

Research outputs of bio degradable polymers

- A study published in the Journal of Experimental Agriculture International found that chitosan-based conditioners enhanced the shelf life of amaranth leaves by reducing post-harvest wilting
- Trials conducted in Tamil Nadu with biodegradable hydrogel with vermicompost combinations showed a 60% higher marketable yield of fenugreek compared to untreated control.
- A research article published in Food chemistry inferred that chitosan could act as an attractive preservative agent for postharvest green asparagus because of its antifungal activity and its ability to stimulate some defense responses during storage.

Environmental impact and sustainability on using bio degradable polymers

The beauty of biodegradable soil conditioners lies in their closed loop life cycle. Once their purpose is over:

- They break down into harmless carbon dioxide, water and biomass
- Enrich soil organic matter
- Leave no microbial residues behind

Use of biodegradable polymers promotes

- Reduced dependency on synthetic fertilizers
- Less groundwater depletion due to improved water-use efficiency
- Healthier ecosystem with thriving soil biodiversity

Moreover, these polymers align with sustainable certification programs and organic farming standards, making them ideal for certified vegetable growers and exporters.

Challenges and Future outlook

The bio degradable polymer concept is widely followed in many foreign countries. In India, the awareness regarding the use of bio degradable polymers must be spread among farmers. There is a need for guidelines and government policies to support adoption of such technology. Biodegradable soil conditioning polymers offer a rare win-win: they nourish both the crop and the earth For leafy vegetables, these polymers provide a reliable, eco-safe path to higher yields, better quality and reduced environmental impact.

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KVKs Promoting Integrated Farming Systems (IFS)

[1]Dr.E.Shirin Hima Bindu*, [2]Dr. Gautam Veer Chauhan, [3]Rita Fredericks
[1]Assistant Professor, College of Community Science, Hyderabad, PJTAU
[2]Subject Matter Specialist (Agronomy) ICAR-CRIDA, KVK, Ranga Reddy, Hyderabad -501505
[3]CEO, Precision Grow (A Unit of Tech Visit IT Pvt Ltd)

Integrated Farming Systems (IFS) provide an enduring solution to increase farm productivity, income, and efficiency in the use of resources, particularly for marginal and small farmers. Krishi Vigyan Kendras (KVKs) are crucial in propagating IFS through demonstrations, on-farm trials, and capacity-building programs specific to local conditions. Through the combination of crops with livestock, horticulture, fishery, poultry, and recycling of organic waste, the KVKs enable farmers to diversify income, mitigate risk, and attain food and nutritional security. This bulletin focuses attention on the principle, ingredients, replicable models, advantages, and disadvantages of IFS, underlining the strategic position of KVKs in its spread and uptake all over India.

1. Introduction

India's farm scenario is dominated by fragmented and small land holdings, reliance on monsoon rains, decreasing soil fertility, and varying market prices. These together result in volatile income to farmers, particularly small and marginal ones who account for over 85% of the farmers' population. Solving these multi-faceted problems calls for a change of paradigm from monoculture-based to more diversified, robust, and holistic systems. One of the solutions to this problem is the use of Integrated Farming Systems (IFS). Chandran *et.al.* 2023.

IFS is an integrated and holistic approach to farming involving multiple agricultural units like crop production, horticulture, livestock farming, poultry, fishery, apiculture, sericulture, agroforestry, mushroom culture, and organic manure production in a single unit of farm. These enterprises are so interrelated that the byproduct of one becomes the input for another, thereby decreasing the use of external inputs, minimizing the pollution of the environment, and increasing resource-use efficiency. This complementarity enhances productivity, profitability, employment opportunities, and environmental sustainability.

Source: https://www.pashudhanpraharee.com

Krishi Vigyan Kendras (KVKs), instituted by the Indian Council of Agricultural Research (ICAR), are key institutions for promoting and applying IFS in various agro-ecological regions. KVKs provide links between research centers and farmer communities through scientific counsel, demonstrations, and training in farmers' specific conditions for IFS models. Through on-farm trials (OFTs), frontline demonstrations (FLDs), skill development programs, and input support, KVKs have a catalytic effect in helping farmers adopt systems of farming that make the best use of resources and enhance resilience to climatic variability. ICAR-ATARI Reports on IFS (2021–2024). Additionally, IFS encouraged by KVKs not only increases farmers' income but also provides food and nutritional security, empowers

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women, saves biodiversity, and promotes climate-resilient agriculture. As India progresses towards doubling farmers' income and sustainable rural development, IFS through KVKs emerges as a suitable and scalable option.

2. Concept and Components of Integrated Farming Systems

Integrated Farming Systems (IFS) is a dynamic and integrated system of farming in which more than one farm enterprise is integrated on a single farm in order to make optimal use of resources, improve farm productivity, and make it sustainable. The principle is based on the concept of efficient reuse of resources wherein the waste or by-product of one unit is the input for another. Not only does this reduce environmental load, but also raises the economic viability and resilience of the farm, particularly for small and marginal farmers.

KVKs are crucial in the development of IFS through the introduction of model-based suitable enterprises based on location-specific agro-climatic conditions, land size, and farmer preference. The primary elements of IFS are:

Source: https://krishijagran.com

2.1 Crop Production

Cultivation of crops is the backbone of IFS, including cereals (maize, wheat, rice), pulses (lentil, chickpea), oilseeds (groundnut, mustard), and vegetables. KVKs encourage crop rotation, mixed cropping, intercropping, and cultivation of high-yielding and climate-tolerant varieties in order to provide income throughout the year and retain soil fertility.

2.2 Horticulture

Inclusion of fruits (mango, guava), vegetables, spices, and medicinal plants enhances nutritional variety and boosts per unit yield. KVKs assist farmers in the development of orchards, kitchen gardens, and polyhouse farming.

2.3 Livestock

Inclusion of dairy, goatery, poultry, and piggery ensures steady income, organic manure for crops, and encourages nutrient recycling. KVKs provide training in animal husbandry and health care.

2.4 Fishery

Use of farm ponds for fish culture increases water productivity and provides protein-rich food. KVKs assist farmers in composite and integrated fish farming.

2.5 Apiculture and Sericulture

These elements increase pollination, increase crop yields, and provide additional income. KVKs supply bee boxes, training, and assistance in mulberry cultivation in sericulture.

2.6 Agroforestry

Intercropping trees (e.g., neem, subabul) with crops and livestock helps in soil conservation, climate management, and extra timber/fuelwood income.

2.7 Vermicomposting and Biogas

Farm waste recycling to organic manure and energy minimizes reliance on chemicals and enhances energy autonomy and soil health.

3. Role of KVKs in Promoting Integrated Farming Systems (IFS)

Krishi Vigyan Kendras (KVKs) are key institutions in the Indian extension system of agriculture, acting as a catalytic agent to convert subsistence farming into sustainable and diversified livelihood enterprises. Under the Integrated Farming Systems

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(IFS) platform, KVKs function as the facilitators of technology transfer, demonstration, capacity development, and entrepreneurship development for farmers. Dar *et.al.* 2018.

3.1 On-Farm Trials (OFT) and Frontline Demonstrations (FLDs

KVKs carry out OFTs for evaluation of the feasibility of different IFS models under prevailing conditions. These trials assist in determining favorable enterprise combinations such as rice-fish-duck, maize-goat-pigeonpea, or banana-poultry-vermicompost systems. FLDs are carried out to showcase the economic and ecological advantages of such systems on farmers' fields directly, making them more acceptable and adopted.

3.2 Capacity Building and Skill Development

KVKs hold training camps for farmers, rural youth, and farm women regularly to develop hands-on skills in diversified farm enterprise management. These consist of training in dairy farming, backyard poultry, organic composting, mushroom culture, apiary management, and integrated nutrient and pest management.

3.3 Resource Centre and Input Support

Many KVKs function as resource hubs, providing quality seeds, planting materials, bio-fertilizers, farm implements, and extension literature. They also establish model IFS units on their premises, allowing farmers to observe best practices and replicate them on their own farms.

3.4 Extension and Advisory Services

KVKs have a combination of conventional and advanced communication instruments for reaching farmers. They organize farm visits, field days, exposure tours, and farmer-scientist interactions. ICT instruments such as mobile apps, WhatsApp groups, and video conferencing are also employed for timely advisory services.

3.5 Women Empowerment through IFS

Identifying the contribution of women in farming, KVKs augment Self-Help Groups (SHGs) by imparting training in kitchen gardening, value addition, mushroom cultivation, poultry rearing, and home-based agro-enterprise, thus improving household income and nutrition.

4. Success Stories and Models

Integrated Farming Systems (IFS) propagated by KVKs have been successfully demonstrated in various agro-ecological zones of India. These zonal models, apart from ensuring more efficient use of resources, also increase farm profitability and sustainability. The following are some success stories that feature the suitability and effectiveness of IFS models designed and demonstrated by KVKs. Sheikh *et.al.* 2021.

4.1 Eastern India: Rice–Fish–Vegetable Model

In the flood-prone and water-rich regions of Odisha and West Bengal, KVKs have introduced the rice–fish–vegetable model. Farmers cultivate rice in the main field while the surrounding bunds are used for vegetables, and fish are reared in adjacent water bodies or in deepened sections of the rice fields. This system has helped farmers increase their income by 2.5 times compared to mono-cropping. It ensures better nutrient recycling, improves water productivity, and enhances household nutrition.

4.2 Western India: Horti–Livestock Integration

Water conservation is a serious problem in the dry and semi-dry areas of Rajasthan. KVKs in the area have been successful in demonstrating pomegranate orchards coupled with goat farming and vermicomposting. The livestock part offers steady income and organic manure, while horticulture offers high returns in terms of money per unit of water. This model ensures effective use of water, reduction of input cost, and diversification of income in dryland regions.

4.3 Southern India: Banana–Poultry–Vermicompost System

In Andhra Pradesh and Tamil Nadu, a model that integrates banana farming, backyard poultry, and vermicompost has been made popular by KVKs. Poultry manure is utilized during composting, while the compost is sprayed on banana crops, minimizing the use of chemical fertilizers. Organic farming, use of low-cost inputs, and regular cash inflows from various sources are promoted by the model.

4.4 North-Eastern India: Integrated Hill Farming

In Nagaland and Meghalaya's hilly landscapes, KVKs have favored integrated models encompassing piggery, fishery, and horticulture. Such systems make efficient use of sloped land as well as community ponds. The strategy offers employment throughout the year, enhances food and nutritional security, and makes efficient use of local biodiversity.

5. Advantages of IFS Encouraged by KVKs

Integrated Farming Systems (IFS) models encouraged by Krishi Vigyan Kendras (KVKs) have a lot of economic, environmental, and social advantages for farmers, particularly small and marginal farmers. By combining crop production with allied activities like livestock, poultry, fishery, horticulture, and composting, farmers get increased productivity through the judicious use of land, labour, and water. Kumar *et.al.* 2020.

IFS strengthens farm revenue through the generation of multiple sources of revenue, thus providing economic stability and minimizing reliance on a single crop. Diversification under IFS considerably reduces production risk and protects against crop failure attributable to pests, disease, or climatic stress.

The system focuses on recycling nutrients, minimizing the use of external inputs, thereby enhancing environmental sustainability. It also provides employment throughout the year, checked rural migration. Significantly, IFS guarantees nutritional security by providing a range of food commodities—such as cereals, pulses, milk, eggs, vegetables, and fruits—at the household level, thus enhancing diet quality and health.

6. Challenges and Way Forward

Though IFS has huge potential for enhancing the livelihood and sustainability of marginal and small farmers, some practical constraints are yet to be overcome for large-scale adoption. Addressing them needs to be a multi-dimensional process that involves policy reforms, institutional assistance, and farmer-oriented interventions in the rural areas guided by KVKs.

6.1 Challenges

- Limited Awareness: Smallholders lack the knowledge of the IFS approach and the long-term advantage. Limited exposure to successful models usually contributes to unwillingness to adopt diversified farming.
- Initial Capital Investment: Creating infrastructure for business units like dairy units, fish ponds, vermicompost pits, or orchards involves initial money outlay, which is usually not accessible to poor farmers.
- Unavailability of Market Linkages: Even if farmers practice IFS, selling the produce of various enterprises (such as eggs, milk, fish, vegetables) becomes a problem because of limited access to marketplaces, storage, and transport facilities.
- Knowledge Gaps: It takes technical skills, planning, and knowledge to run a system of multiple enterprises. Most farmers are confused about the difficulty of integrating and linking diverse components in an efficient manner.

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6.2 Recommendations

- Policy Support: Government must launch targeted schemes or sub-components of current programs such as RKVY, PM-KUSUM, or MIDH to promote IFS adoption. Incentives for water harvesting systems, composting facilities, and interlinked enterprises must be given.
- Credit and Insurance: Financial institutions and banks must come up with customized credit and insurance products to assist IFS entrepreneurs with ease of repayment terms and risk protection for multi-enterprise networks.
- Capacity Building: KVKs need to persistently provide structured and periodic training programs, exposure visits, and skill modules to assist farmers in effectively managing IFS units.
- Market Access: Organization of FPOs and enabling direct marketing forums can assist farmers in aggregating and jointly processing, packaging, and marketing their diversified products at more remunerative prices.
- Research-Extension-Farmer Linkage: A stronger feedback mechanism should be developed where farmers' field experiences inform research priorities, and KVKs act as the conduit for rapid transfer of context-specific technologies.

7. Conclusion

Krishi Vigyan Kendras play a key role in bringing the idea of Integrated Farming Systems to reality. Through innovation, training, demonstrations, and extension guidance, KVKs have equipped thousands of farmers to shift from subsistence to sustainable and remunerative farming. To take IFS mainstream at scale, a convergent, participatory, and ecosystem-sensitive approach is needed, with KVKs leading this change

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Integrating Horticultural Innovation and Resource Engineering for Sustainable Agricultural Growth

Ms. Prachee Mishra[1] and Dr. Vipin Kumar Mishra[2]
[1]Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.)- 492012, INDIA
[2]ICAR-Indian institute of Soil & Water Conservation Dehradun (UK)-248195, INDIA

India's agricultural growth trajectory from food-deficient in the 1960s to a global food surplus contributor today has been powered by strategic investments in research, technological innovations, and policy reforms. However, this remarkable progress has also intensified pressure on natural resources, with widespread soil degradation, groundwater depletion, and increasing vulnerability to climate variability. As the country transitions toward a nutrition-sensitive and climate-resilient agricultural system, integrating horticultural innovation with resource-conserving engineering practices becomes imperative. This article explores how the convergence of fruit science and soil and water engineering can drive sustainable agricultural intensification. It highlights the pivotal role of conservation technologies such as micro-irrigation, protected cultivation, contour bunding, rainwater harvesting, and agroforestry in improving resource-use efficiency, enhancing climate resilience, and ensuring long-term soil and water security. The analysis underscores the need for policy convergence, institutional support, and farmer-centric extension systems to scale these innovations effectively. By aligning horticultural advancements with eco-engineering solutions, this article offers a roadmap for transitioning toward a more productive, sustainable, and climate-adaptive Indian agriculture, ensuring food and nutritional security without compromising environmental integrity

1. Introduction

India’s agricultural sector has undergone a profound transformation since the 1960s, evolving from a food-deficient nation heavily reliant on imports to a food-surplus country that now exports a range of agricultural commodities. This shift from low productivity to high-tech, input-intensive farming was made possible through a combination of strategic public investment in agricultural research and development (R&D), the Green Revolution, progressive policy support, and the adoption of modern technologies at the grassroots level. However, this success story, while commendable, has come with significant ecological costs—overexploitation of groundwater, depletion of soil fertility, and widespread land degradation.

As we enter an era marked by climate variability, erratic monsoons, and mounting resource stress, it is imperative to rethink and realign our agricultural practices. Sustaining past gains while ensuring future food and livelihood security demands a paradigm shift—one that places soil and water conservation at the center of agricultural planning. This is where agricultural engineering plays a pivotal role. Techniques such as rainwater harvesting, micro-irrigation, farm ponds, check dams, and precision land leveling not only improve productivity but also enhance resource-use efficiency and climate resilience. Integrating these engineering solutions with policy, extension, and farmer participation will be key to fostering a more sustainable and equitable agricultural future for India.

I. Agricultural R&D: A Catalyst of Productivity and Resilience

India's investment in agricultural research and development (R&D) has grown more than tenfold from ₹11.3 billion during 1966–1980 to ₹116.3 billion in 2014–2024 (at 2011–12 constant prices) reflecting a strong national commitment to science-driven agricultural advancement. This sustained

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R&D focus has paid rich dividends: annual foodgrain production increased significantly from 2.7 million tons during 1966–1980 to 8.1 million tons in 2014–2024, establishing India as a food-secure nation.

Yet, the next phase of agricultural development must shift from purely production-centric goals to a more conservation-oriented approach. Continuing to expand food output while neglecting the health of natural resources especially soil and water risks undermining the very foundation of past achievements. To ensure long-term sustainability, agricultural growth must now be rooted in the principles of conservation agriculture.

Agricultural engineering solutions such as efficient irrigation systems, soil erosion control structures, watershed management, and precision land shaping must take center stage. These technologies not only enhance resource use efficiency but also protect against land degradation, mitigate climate impacts, and sustain soil fertility. By aligning future strategies with conservation science, India can secure both agricultural productivity and environmental resilience for generations to come.

II. Soil Conservation: Protecting the Productivity Engine

Soil erosion, nutrient depletion, and land degradation affect nearly 30% of India's total land area, threatening the very basis of agriculture. The unchecked loss of topsoil due to water runoff reduces fertility, affects root development, and increases reliance on chemical fertilizers.

Engineering-based soil conservation practices have proven effective in reversing degradation:

- Contour bunding and graded bunds reduce runoff and increase infiltration on sloping lands.
- Terracing, especially in hilly regions, helps prevent sheet and rill erosion.
- Vegetative hedges, grassed waterways, and cover cropping provide physical barriers to erosion while enriching the soil.
- Gully plugs and check dams stabilize fragile catchments.

Such interventions, when implemented through watershed management programs, also restore the hydrological cycle recharging groundwater, improving base flow, and enhancing crop resilience.

III. Water Conservation: Sustaining the Lifeline of Agriculture

India accounts for 17% of the world’s population but only 4% of its freshwater resources, highlighting a stark water scarcity challenge. The overuse of groundwater, inefficient irrigation, and erratic monsoon patterns are stressing India’s water systems.

As milk production increased from 0.9 to 10.2 million tons annually (1966–2024), and horticulture growth from 1.3 to 7.5 million tons, the demand for water-intensive crops and livestock has grown. This highlights the urgent need for water-use efficiency.

Engineering solutions for water conservation include:

- Drip and sprinkler irrigation systems, which can reduce water use by 40–60% compared to traditional flood irrigation.
- Percolation tanks, farm ponds, and recharge pits that harvest rainwater and improve groundwater levels.
- Subsurface drainage systems to manage waterlogging in high-rainfall or poorly drained areas.
- Laser land leveling, which ensures uniform water distribution and reduces water loss.

Integrating these measures with watershed-level planning, supported by remote sensing and GIS tools, enables localized and scalable water management.

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IV. Horticulture and Livestock: Balancing Nutrition with Resource Efficiency

The transition from staple cereals to high-value crops such as fruits, vegetables, and dairy products marks a significant evolution in India's agricultural landscape one that is essential for ensuring national nutrition security. While horticulture now surpasses food grain production in terms of growth, it brings new challenges due to its heightened sensitivity to microclimatic variations, pest outbreaks, and fluctuating soil moisture levels.

To address these vulnerabilities, the adoption of climate-resilient practices becomes crucial. Protected cultivation systems such as polyhouses and net houses—combined with precision techniques like micro-irrigation, soil mulching, and integrated organic nutrient management, can stabilize production, enhance crop quality, and reduce environmental stress. These innovations allow for intensive cultivation with efficient use of land and water resources, particularly in marginal and peri-urban areas.

In the dairy sector, sustainable intensification is equally important. Integrating fodder-based agroforestry systems, establishing silage pits for feed security, and promoting livestock waste recycling through biogas and composting units can significantly lower environmental footprints. These practices not only enhance productivity and reduce dependency on external inputs but also help close the nutrient loop, contributing to a circular bioeconomy. Together, these interventions make agriculture more resilient, profitable, and environmentally sustainable.

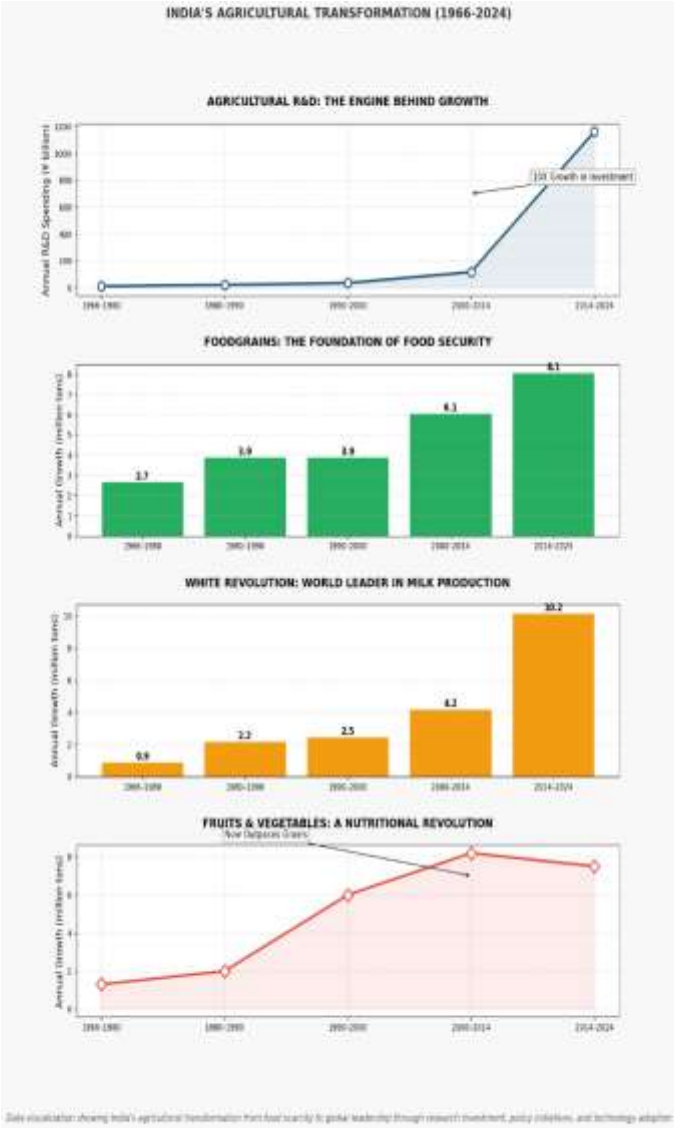

Figure 1: India's Agricultural Transformation Across Key Sectors (1966-2024)

V. Climate Adaptation Through Engineering Innovation

With climate change intensifying rainfall variability and drought frequency, the role of climate-resilient agricultural infrastructure is more critical than ever:

- Rainwater harvesting structures buffer dry spells and reduce flood peaks.
- Contour trenches and staggered pits on degraded lands enhance moisture retention.

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- Mobile irrigation systems, solar pumps, and IoT-based irrigation scheduling are revolutionizing precision agriculture.

Moreover, using decision-support tools, real-time sensors, and crop-weather modeling can help farmers make informed choices on crop selection, planting schedules, and input use—minimizing risks and maximizing productivity.

VI. Policy and Extension: The Missing Link

No conservation strategy can succeed without institutional backing. Policies must incentivize:

- Adoption of soil health cards, water budgeting tools, and on-farm trials.
- Integration of agricultural engineering graduates in Krishi Vigyan Kendras (KVKs) and watershed development teams.
- Upscaling successful farmer-led conservation models through financial support and capacity-building.

Furthermore, convergence between schemes like PMKSY, MGNREGA, RKVY, and National Watershed Development Programme can bring scale, synergy, and sustainability.

Conclusion:

Indian agriculture has undergone a transformative journey from food scarcity to surplus, largely due to enhanced public investment, technological advancement, and infrastructure development. However, this growth has come at the cost of overexploited natural resources, particularly soil and water. With the increasing pressure of population growth, climate change, and environmental degradation, the focus must shift from mere productivity to sustainable resource management.

Engineering-based solutions—such as check dams, contour bunding, farm ponds, drip irrigation, and watershed development—are essential for conserving soil and optimizing water use. These interventions not only improve productivity but also ensure long-term sustainability, especially in rainfed and resource-stressed regions.

As horticulture, livestock, and climate-resilient cropping systems gain importance, there is a need for integrated, conservation-focused approaches supported by real-time data, advanced modeling, and farmer-centric extension services. Strengthening institutional support, promoting participatory planning, and incentivizing resource conservation are crucial for scaling such models.

In summary, the future of Indian agriculture lies in a holistic, engineering-enabled paradigm that conserves soil and water while enhancing resilience and productivity. A shift towards resource-efficient, climate-smart, and ecologically sound practices is critical for ensuring food, water, and livelihood security in the decades to come.

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Smart Pest Monitoring: New Tools Empowering Agri-Entrepreneurs

Sharmistha Mandal[1]

[1]Ph.D. Research Scholar, Department of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal

Agriculture is at the crossroads of a technological transformation, and at the heart of this change lies one of farming's oldest adversaries—insect pests. From devouring standing crops to spreading plant diseases, pests pose a recurring threat to food security, farmer income, and national productivity. Traditional methods, which rely on chemical pesticides, are becoming increasingly insufficient due to climate change and pest resistance. However, innovations in smart pest monitoring, driven by AI, IoT, and mobile technology, are redefining pest management and opening up new opportunities for agri-entrepreneurship. These tools enable farmers to make informed decisions and allow startups to deliver scalable, tech-driven solutions.

Why Smarter Pest Monitoring is the Need of the Hour?

Pest invasions, such as the fall armyworm and desert locusts, have severely impacted crops in India, exacerbating the problem with climate change. The widespread use of traditional pesticides has led to the development of resistance and declines in beneficial insects. However, modern solutions like real-time data and precision control methods help reduce pesticide use, protect crop yields, and lower costs, while also creating opportunities for agri-tech entrepreneurs.

Cutting-Edge Tools for Pest Detection & Monitoring:

1. AI-Powered Pest Detection Apps

Mobile-based pest diagnosis tools have revolutionized field-level scouting. **Example**:

Plantix (Germany/India) uses smartphone cameras and AI to identify over 400 pests and diseases and offers treatment suggestions. Widely adopted across Madhya Pradesh and Maharashtra.

AgriApp and **KrishiHub** offer pest advisories in vernacular languages for rural outreach.

2. IoT-Enabled Smart Traps

Equipped with cameras, pheromones, and sensors, these traps capture insects, count them, and transmit data to cloud platforms for early warning. **Example**:

Trapview (Slovenia) devices, piloted in Indian orchards, automatically detect moths and fruit flies and alert growers via mobile dashboards.

Eruvaka Technologies (Andhra Pradesh) builds smart aquaculture and field pest monitoring devices powered by solar energy.

3. Drone Surveillance & Targeted Spraying

Unmanned aerial vehicles (UAVs) detect pest hotspots and deliver precision biopesticide spraying. **Example**:

Garuda Aerospace and **Marut Drones** were key players in India's locust management in Rajasthan (2020–21), helping reduce pesticide wastage and labor costs.

Agribot, an Indian startup, provides drone-as-a-service (DaaS) for pest scouting and treatment in paddy and sugarcane fields.

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4. Predictive Pest Forecasting Models

These tools combine weather, crop, and pest biology data to predict outbreaks days or weeks in advance. **Example**:

ICAR-NCIPM's FOREWARN system forecasts major pests like stem borers and fall armyworm in rice and maize-growing regions of Odisha and Tamil Nadu.

SatSure, a Bengaluru-based agri-analytics company, uses satellite data to offer pest risk zones for insurers and agribusinesses.

5. Sensor-Based Pheromone Traps

Sensorized pheromone traps digitize pest counts and alert farmers before infestations reach economic threshold level. **Example**:

Fasal, a precision farming startup, uses weather-linked traps in pomegranate and apple orchards for timely interventions.

From Farm to Fortune: Entrepreneurship Opportunities: The emergence of these tools has led to a new wave of agripreneurs who are converting pest problems into business possibilities:

Business Idea	Startup/Example	What They Do
Drone Services	Marut Drones, Garuda Aerospace	Pest scouting, spraying biopesticides
Smart Trap Sales	Eruvaka, Agritech startups in Gujarat and Telangana	IoT pest trap manufacturing for fruit and cotton pests
Biopesticide Formulation	BioPrime AgriSolutions	Makes biostimulants and natural pest repellents
Pest Advisory Apps	KrishiHub, Plantix	Mobile-based pest alerts and crop health support
Agri Analytics	SatSure, CropIn	Predict pest outbreaks using weather, satellite & field data

TNAU students have created a Bluetooth-enabled pheromone trap that alerts farmers to rising moth counts. This low-cost tool received awards at the 2024 ICAR Innovation Challenge and is currently being tested in Tamil Nadu's cotton belts.

Government & Ecosystem Support

Schemes like **RKVY-RAFTAAR**, **Startup India**, **AGNIi**, and **Atal Incubation Centres** are supporting pest-tech innovation through seed funding, training, and incubation. Krishi Vigyan Kendras (KVKs) and Agricultural Universities across India are also partnering with startups to field-test smart pest tools.

Turning a Threat into an Opportunity

Pest outbreaks will always be a challenge in agriculture, but our response can shape food security. With advancements in smart pest monitoring, we are shifting from reaction to prediction and from chemicals to precision. This shift represents not just a solution, but a movement. For India's agri-entrepreneurs, pests are now seen as catalysts for innovation and new business opportunities.

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IoT-Integrated Biosensors in Monitoring Food Safety

Shikshita Jain[1*], Bharat Taindu Jain[2]
[1]Department of Physics, Panjab University, Chandigarh-160014 (INDIA)
[2]Department of Genetics and Plant Breeding, CCS HAU, COA, Bawal

Globally, there is growing interest in integrating biosensors and the Internet of Things (IoT) into food packaging to quickly improve food safety and traceability. One of the most fascinating topics in the digital and virtual world right now is the IoT. Food systems can use biosensors to track, detect, and pinpoint early indicators of food freshness or spoiling. When used in conjunction with the IoT, these biosensors can help transmit data through IoT networks (shown in Figure 1), giving stakeholders at every level of the food supply chain real-time information about the conditions of food storage and transit, enabling proactive decision-making. In contrast to traditional food inspection technologies, which are restricted to evaluating weight, volume, color, and physical appearance, the integration of biosensors with the IoT could leverage artificial intelligence (AI) to improve food safety, quality, and security in the food sector.

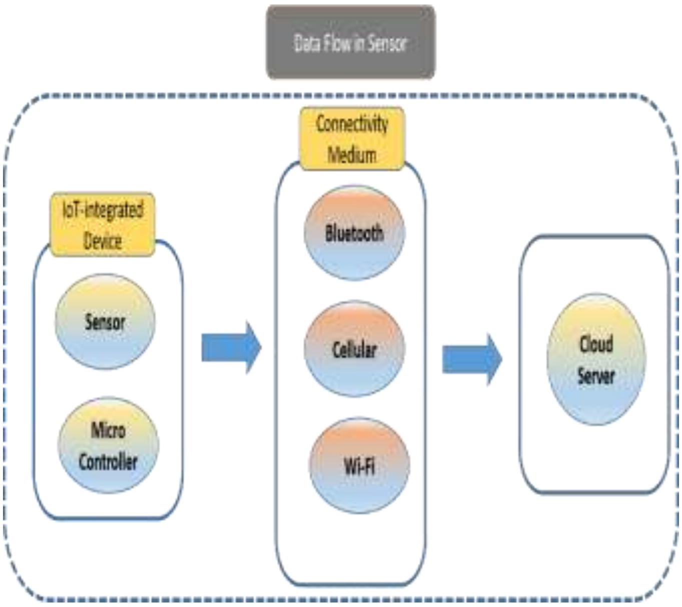

Figure1: Transmission of Data via IoT-integrated biosensor

IoT-integrated Biosensor

IoT-integrated biosensors are devices that integrate:

- biological sensing components, such as DNA probes, enzymes, and antibodies,
- thermal, optical, or electrochemical signal transducers, and
- modules for wireless communication (such as Bluetooth, RFID, Wi-Fi, or ZigBee).

These sensors identify particular chemical or biological markers in food items and transmit data in real time, be accessed remotely, do predictive analytics, and automate food safety procedures.

Key Benefits of Real-Time Monitoring with IoT Integration:

1. Temperature, humidity, pH, gas emissions (such as ethylene or ammonia), microbiological contamination, and other factors can all be continuously and lively detected without the need for manual sampling.
2. When food safety criteria are crossed, data-driven triggers can automatically send alerts through dashboards or mobile apps, allowing for prompt remedial action.
3. From any location at any time, supply chain participants can keep an eye on spoiling risk or storage conditions.
4. Every measurement can be kept for later use for blockchain-based authentication, tracking, or regulatory audits.

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5. By integrating machine learning models, it is possible to estimate shelf life, predict rotting occurrences, or identify contamination patterns, all of which support preventive maintenance.

Challenges

- The high cost and technical complexity of IoT-integrated biosensors frequently make it difficult for them to integrate with current food packaging systems.
- In order to detect and monitor food pathogens, their monitoring, and the conditions of packaged food, biosensors require a power supply. They also need to gather data on packaging conditions and send it via the IoT for analysis, which entails a lot of tasks.
- These technical systems of IoT-integrated biosensors must frequently rely on wireless connection, which is susceptible to unauthorised access, hacking, and data breaches, in order to gather and transmit real-time data on food quality and safety.

Conclusions and Future Perspectives

An innovative approach to food system monitoring is represented by IoT-integrated biosensors. By combining digital connection, analytics, and sensitive sensing technologies, they offer a strong foundation for avoiding contamination, improving the traceability of food, and cutting back on waste. The high cost for implementing IoT connectivity with the biosensor is a major obstacle that must be managed for the food industry. To overcome these obstacles, academic and industry partnership is needed for research and development. Furthermore, in order to extend the reach of these technologies to underserved markets, it is necessary to address regional differences in infrastructure and consumer awareness. The emergence of numerous engineering technologies and nanomolecules, such as blockchain, robots, and automation, along with sensors and actuators in the food and agricultural industries, presents opportunities for innovation that can influence the capabilities of IoT-enabled biosensors and develop a method that not only engages consumers but also ensures food safety.

These technologies have the potential to become crucial components of smart agriculture, and food processing that are more widely available and scalable. It is anticipated that advancements in material sciences, bioengineering, and nanotechnology will result in biosensors that are more robust, accurate, and sensitive. Utilising cutting-edge technology like machine learning (ML) and artificial intelligence (AI) will enhance data processing and provide better distribution and storage choices. Addressing global issues like food shortages and climate change will require cooperation between businesses, governments, and academic institutions. Smart packaging foods with IoT-enabled biosensors has the potential to become a key technology for creating resilient, and sustainable, food systems by utilising the synergistic potential of cross-sector alliances and multidisciplinary research.

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Cryopreservation of Sugarcane Explants for Germplasm Conservation

[1]Dr. Anil Kumar*, [2]Manjul Jain, [3]Dr. Sultan Singh
[1,2]Assistant Professor, Department of Agronomy, School of Agriculture, Eklavya University Damoh, Madhya Pradesh-470661
[3]Assistant Professor, Department of Agriculture, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala-133207, Haryana, India

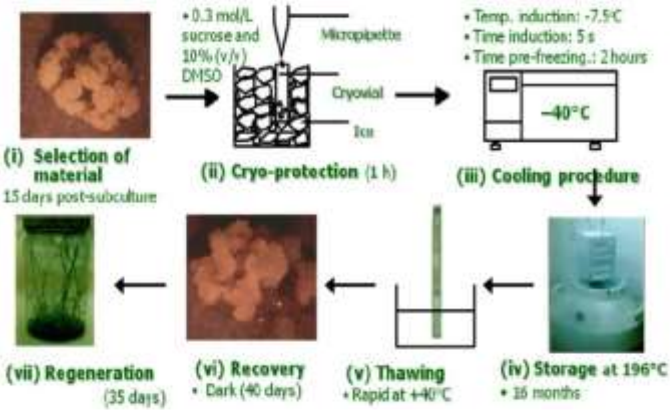
Cryopreservation is a useful approach for long-term conservation of sugarcane germplasm by maintaining explants like shoot tips, axillary buds, and embryogenic callus at ultra-low temperatures (−196°C). The method stops cellular metabolism, maintaining the genetic stability and viability. It facilitates secure international germplasm exchange, less reliance on field gene banks, and a safe backup against biotic and abiotic stresses, benefiting breeding and conservation.

1. Introduction

Sugarcane (Saccharum spp.) is an important industrial crop grown on a large scale in tropical and subtropical areas for sugar, ethanol, and other by-product production. It significantly contributes to the agricconomomy and offers raw material to numerous agro-based industries. In contrast to seed crops, sugarcane is propagated vegetatively by using stem cuttings, and thus it is extremely susceptible to the build-up of systemic diseases from one planting season to another. Also, sugarcane germplasm is cumbersome and perishable, resulting in great difficulties in its long-term conservation by traditional means. Rajasekharan *et.al.* 2015. Conventional field gene banks are susceptible to climatic changes, infestations by pests, outbreak of diseases, and need high maintenance, space, and labor. So, sophisticated and secure techniques such as cryopreservation have assumed significance for sustainable conservation.

1.1 Need for Germplasm Conservation

The maintenance of plant genetic resources is an essential aspect of sustainable agriculture and future crop improvement schemes. Germplasm harbors the genetic diversity needed for the development of new varieties with resistance to biotic and abiotic stresses. In sugarcane, which has a restricted genetic base in view of vegetative propagation, maintenance of genetic diversity assumes greater significance. But traditional conservation systems like in vivo field maintenance not only take a lot of labor and money but are also risky because they are subjected to environmental stresses. To counteract the above drawbacks, cryopreservation - preservation of living cells, tissues, or organs at extremely low temperatures (−196°C with liquid nitrogen) - is coming forward as a reliable means to maintain long-term and stable storage of germplasm with no alteration of genes. Banasiak *et.al.* 2017.



Sourece: https://www.researchgate.net

1.2 Purposes of Cryopreservation in Sugarcane

- Provide long-term, stable conservation of elite genotypes and wild relatives.

- Enable safe and secure international transfer of sugarcane genetic material.
- Offer a secure backup system for precious breeding lines and pathogen-free stock material for multiplication.

2. Principles and Techniques of Cryopreservation

2.1 Principle of Cryopreservation

Cryopreservation is a biotechnological method to conserve the viability of biological tissues under ultra-low temperatures, usually liquid nitrogen at −196°C. In such cold temperatures, all of the physiological and metabolic activity of the preserved cells is essentially brought to a stop, maintaining the tissues in suspended, viable form indefinitely. The secret to successful cryopreservation is avoiding the growth of ice crystals, which cause cell structures to be harmed. By dehydrating the cells slowly and carefully, as well as employing the use of cryoprotectants, cellular structure is preserved during freezing and upon thawing. After thawing and culturing on the right medium, the cells or tissues return to normal growth and development, finally regenerating into whole, viable plants. Gonzalez-Arnao *et.al.* 2006.

2.2 Plant Material Used in Sugarcane Cryopreservation

Different types of explants can be employed in the cryopreservation of sugarcane, depending on the procedure and conservation objective:

- Shoot tips / Apical meristems: Dividing cells that are suitable for virus-free regeneration.
- Axillary buds: Widely utilized in clonal propagation as well as germplasm exchange.
- Embryogenic callus: Ideal for genetic transformation and somatic embryogenesis.
- Somatic embryos: Yield high regeneration capability with clonal fidelity.

2.3 Major Steps in the Cryopreservation Process

1. Selection of Healthy Explants

Only disease-free, actively growing, and young tissues are chosen to achieve high post-thaw survival.

2. Pre-culture

Explants are maintained on osmoprotectant-supplemented medium like sucrose or mannitol to create dehydration tolerance and precondition cells for cryoprotection.

3. Cryoprotection

Use of cryoprotective agents (CPAs) such as DMSO (dimethyl sulfoxide), glycerol, or Plant Vitrification Solutions (PVS1, PVS2, PVS3), which minimize the chances of ice crystal formation due to induced vitrification.

4.Freezing

Two primary methods:

- Slow freezing: Gradual rate of cooling to −40°C prior to immersion in liquid nitrogen.
- Vitrification: Rapid freezing that converts cellular water into a glassy amorphous phase without ice formation.

5.Storage

Cryopreserved samples are preserved in either:

- Liquid nitrogen is used at −196°C for total metabolic arrest.
- Vapor phase liquid nitrogen (−150°C to −170°C) to reduce the risk of contamination.

6. Look into Thawing and Recovery

The rapid warming (generally between 37°C to 45°C) is essential for avoiding recrystallization. Explants are subsequently washed to eliminate toxic CPAs and placed in recovery media.

7. Regeneration

Explants are cultured under optimized environmental conditions to induce the formation of shoots and roots. Regenerated plantlets are acclimatized and shifted to soil or greenhouse conditions.

3. Cryopreservation Methods Utilized in Sugarcane

Cryopreservation protocols have been rigorously optimized in sugarcane to achieve maximum tissue viability and regeneration of the plant upon ultra-low temperature storage. These methods aim to inhibit the development of intracellular ice, which causes cell membrane and structure damage in the freezing-thawing process. Various cryopreservation approaches are utilized depending on the explant type, targeted scale, and resources available.

3.1 Vitrification

Vitrification is the most commonly used technique for the cryopreservation of sugarcane shoot tips and meristematic tissues. This involves subjecting explants to high-concentration cryoprotectant solutions like Plant Vitrification Solution 2 (PVS2). These solutions dehydrate the cells and create a glassy condition on quick cooling in liquid nitrogen, preventing ice crystal formation. The technique is preferred due to its velocity, reliability, and lack of equipment needs. Nevertheless, the toxicity of the very concentrated solutions and the requirement for experienced, time-consuming handling are its main disadvantages.

3.2 Encapsulation-Dehydration

In this technique, explants—usually axillary buds—are encapsulated in calcium alginate beads and slowly dehydrated with osmotic agents or air drying. Encapsulated and dehydrated tissues are then frozen in liquid nitrogen. This method has structural support and controlled dehydration and is less stressful. Though less efficient than vitrification, it is helpful for gene bank conservation because of its structural protection and moderate success. The process is more time- and labor-consuming, though.

3.3 Droplet Vitrification

A method of fast cooling, droplet vitrification entails putting explants into small droplets of vitrification solution on strips of aluminum foil and instantaneously plunging into liquid nitrogen. The extremely fast cooling rate slows down the formation of ice greatly and improves survival. A high rate of regrowth (up to 90%) is available with this method, but precision requirements make it better for small-scale applications.

3.4 Encapsulation-Vitrification

This dual approach incorporates alginate encapsulation and vitrification treatment, both physical protection and dehydration at high rates. It is easy to handle on a large scale and transport, but the process can be complicated and can be subject to non-uniform diffusion of cryoprotectants, so one must optimize it carefully for each genotype.

4. Factors Affecting Cryopreservation Success

The success of cryopreservation in sugarcane is determined by a range of factors that determine the survival, viability, and regenerative ability of preserved explants. A comprehensive knowledge of these factors enables the creation of effective and genotype-specific procedures for long-term storage of germplasm.

4.1 Explant Size and Type

One of the most important factors that determine the success of cryopreservation is the choice of good explant material. For sugarcane, smaller shoot tips or apical meristems of approximately 1–2 mm in length are desirable, since these are composed of actively dividing, metabolically active cells with high capacity for regrowth. Smaller explants are more easily dehydrated and vitrified efficiently and with minimal chance for intracellular ice formation.

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Larger tissues have a greater water content and a higher likelihood of ice damage upon freezing and thawing.

4.2 Pretreatment Conditions

Pre-treatment of explants before cryopreservation is required to improve their dehydration and freezing stress tolerance. This is usually achieved by growing the tissues on medium supplemented with osmoprotectants like sucrose or mannitol. Osmoprotectants decrease the water content in cells and stabilize membranes and proteins against future cryoprotectant treatment and freezing processes. The concentration and duration of pre-treatment need to be well-optimized to prevent osmotic shock and toxicity.

4.3 Composition of Cryoprotectants

Cryoprotective agents like PVS2 and PVS3 are critical in inhibiting ice crystal development. But their toxicity counteracts their efficacy. CPAs have the ability to destabilize cellular architecture upon extended exposure, so the composition as well as the duration of exposure needs to be optimized for maximum protection with minimal toxicity.

4.4 Rate of Cooling and Thawing

A high cooling rate, particularly in vitrification and droplet vitrification processes, prevents intracellular ice formation. Quick thawing is also necessary to prevent recrystallization. Incorrect temperature transitions during freezing or thawing can greatly lower the viability of the explant.

4.5 Genotype Specificity

Various sugarcane genotypes can react variably to cryopreservation procedures on the basis of intrinsic physiological or biochemical variations. It is thus usually important to adapt the cryopreservation procedure to each genotype in case of preserving a diverse collection of germplasm.

5. Applications and Benefits

Cryopreservation has become a versatile tool in contemporary plant biotechnology, with a variety of uses and advantages, especially in vegetatively propagated and genetically complex crops such as sugarcane. Its incorporation into conservation strategies for germplasm offers a dependable, cost-efficient, and secure system for the long-term storage and international exchange of precious genetic resources Jayabose *et.al.* 2024..

5.1 Germplasm Conservation

Cryopreservation allows safe, long-term storage of superior sugarcane genotypes, wild relatives, and pathogen-free tissues without the necessity of frequent subculturing or maintenance under fields. In contrast to traditional field gene banks that are susceptible to pests and diseases, weather conditions, and human mistakes, cryogenic storage is a secure, contamination-free state. This serves to minimize the expenses and manpower involved in the upkeep of living plants and greenhouses, while genetic characters are ensured to be conserved over the long term.

5.2 Exchange of International Germplasm

Cryopreserved tissue, for example, shoot tips and embryogenic callus, is transported safely between nations in cryogenic conditions, with low possibilities of disease transmission. This is particularly beneficial for adherence to international quarantine protocols and phytosanitary standards. By lowering the possibilities of movement of pests or pathogens, cryopreservation facilitates safe and effective global exchange of germplasm, which is critical for collaborative research and breeding projects.

5.3 Breeding Program Support

Breeders are immensely benefited by having genetically stable and uniform material conserved through cryopreservation. Such conserved explants can be activated at will for breeding, selection, or genetic alteration. Cryopreserved embryogenic callus can be used immediately for genetic alteration, mutation breeding, or multiplication by tissue culture, facilitating crop improvement programs.

5.4 Backup During Biotic or Abiotic Stress

Cryopreservation is a biological insurance policy protecting valuable genetic material against such unexpected occurrences as disease outbreaks, weather extremes, or natural disasters. Cryobanks ensure a reliable safeguard so that valuable varieties and wild gene pools are not irrevocably lost to external factors.

6. Challenges, Advances, and Future Prospects

Cryopreservation is extremely promising for long-term conservation of sugarcane genetic resources, but its widespread uptake is currently still constrained by a number of technical and operational issues. Concurrently, advances in the past few years are quickly expanding the efficiency, scalability, and reproducibility of cryopreservation protocols. In the future, developments in biotechnology and the integration of data are anticipated to revolutionize the preservation and use of germplasm around the world. Sarwar *et.al.* 2004.

6.1 Challenges

Although it has advantages, a number of limitations restrict the regular use of cryopreservation in sugarcane:

- Standardization of protocols is still a significant barrier. Sugarcane is genetically heterogenous, and various genotypes react differently to cryopreservation protocols. Consistent methods that perform well across a broad variety base are still being developed.
- The expense of establishing and sustaining cryogenic facilities, liquid nitrogen equipment, and storage systems is considerable. This can limit use in resource-poor institutions or in developing countries.
- Technical expertise is necessary. The procedure involves sensitive manipulation of micro-sized explants, stringent temperature control, and optimal exposure to cryoprotectants, all which need specialized skills and experience.

6.2 Recent Advances

Research and development have brought forth several advancements that are enhancing cryopreservation success:

- Handling of explants by robotic systems and microfluidics is minimizing human error while enhancing throughput.
- Synthetic seed technology, where cryopreserved shoot tips or embryos are encapsulated in protective beads, is also emerging as a double-duty system for storage and propagation.
- Machine learning and AI are now being investigated to fine-tune cryoprotectant compositions, forecast explant viability, and tailor protocols according to genotype-specific responses.

6.3 Future Prospects

With advancing technologies in cryopreservation, their incorporation into national and global conservation programs will be driven faster:

- Regional and international cryobanks for sugarcane would act as safe repositories for genetic diversity for backcrossing and disaster rescue.
- DNA fingerprinting and molecular markers will become routine methods for the determination of genetic fidelity and regenerated plant stability following cryopreservation.

- Traceable, secure, and transparent sharing of conserved material will be made possible through digital germplasm databases, which are interconnected with blockchain technologies, increasing trust and worldwide collaboration.

Conclusion

Cryopreservation is an indispensable tool for sugarcane germplasm conservation. It provides long-term genetic stability, facilitates breeding and biotechnology, and facilitates increased world germplasm exchange. With protocol and technology improvements, cryopreservation will become a foundation for sustainable conservation of sugarcane biodiversity.

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Success Stories of Farmers Trained by Krishi Vigyan Kendra (KVK)

[1]Dr. Dileep Kumar Gupta, [2]Dr. Anil Kumar, [3]Manjul Jain

[1]Teaching Assistant, Deptt. of Agricultural Extension, Institute of Agricultural Sciences, Bundelkhand University, Jhansi (U.P.) – 284128

[2,3]Assistant Professor, Department of Agronomy, School of Agriculture, Eklavya University, Damoh, Madhya Pradesh-470661

Krishi Vigyan Kendras (KVKs) play a vital role in empowering Indian farmers by transferring scientific knowledge and innovative practices to the grassroots level. Through need-based training, frontline demonstrations, and on-farm trials, KVKs enable farmers to adopt improved technologies across crops, livestock, and allied sectors. This article highlights real-life success stories of farmers who have benefited from KVK interventions, resulting in increased productivity, income diversification, and sustainable practices. From precision farming and organic cultivation to integrated farming systems and agri-entrepreneurship, these stories demonstrate the transformative impact of KVKs in building self-reliant and progressive rural communities.

1. Introduction

Krishi Vigyan Kendras (KVKs), established by the Indian Council of Agricultural Research (ICAR), are frontline agricultural extension centers dedicated to transforming Indian agriculture through localized, science-based interventions. Operating at the district level, KVKs bridge the gap between research institutions and farmers by providing hands-on training, on-farm testing (OFT), frontline demonstrations (FLDs), and advisory services tailored to regional agro-climatic conditions. Their primary mission is to empower farmers, rural youth, and women by enhancing their knowledge, skills, and decision-making abilities in agriculture and allied sectors. Through capacity building, KVKs promote the adoption of improved crop varieties, livestock management, integrated farming systems, organic practices, and agri-entrepreneurship. This article presents a compilation of success stories from across the country, showcasing how KVK-trained farmers have significantly improved their productivity, income, and resilience. These stories highlight the pivotal role of KVKs in fostering sustainable rural development and advancing the vision of self-reliant and prosperous farming communities. Bbubaneiwar *et.al.* 2002.

Krishi Vigyan Kendras (KVKs)

Krishi Vigyan Kendras (KVKs) are the backbone of India's agricultural extension system, functioning as the frontline institutions for technology dissemination at the grassroots level. Established under the guidance of the Indian Council of Agricultural Research (ICAR), these centers are strategically located across all agro-climatic zones of the country. Their primary goal is to bridge the gap between agricultural research and farming practices by bringing scientific knowledge directly to the farmer's field. Chakraborty *et.al.* 2025.

KVKs function on the principle of "learning by doing" and "seeing is believing." They are not merely training institutions but act as **knowledge and resource hubs** for farmers, rural youth, and extension workers. Each KVK is equipped with expert staff, demonstration units, laboratories, and farm infrastructure to carry out comprehensive training and field-level interventions.

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Mandates of KVKs

The mandates of KVKs are carefully designed to cater to the diverse and dynamic needs of the rural farming community:

- **On-Farm Testing (OFT):** KVKs test new technologies under real field conditions to assess their feasibility and adaptability before they are recommended for wider adoption. This ensures that only refined, location-specific solutions are passed on to farmers.
- **Frontline Demonstrations (FLD):** FLDs are conducted on major crops, livestock, and farming systems to demonstrate the potential of new varieties and technologies. These serve as live examples for other farmers in the region.
- **Training Programs:** KVKs organize need-based short and long-duration training sessions for farmers, rural youth, and extension personnel on improved agricultural practices, post-harvest technologies, value addition, and enterprise development.
- **Advisory Services:** Through field visits, phone consultations, and mobile advisories, KVKs provide timely guidance to address field-level challenges.
- **Entrepreneurship Development:** By promoting agri-based enterprises like beekeeping, mushroom cultivation, and agro-processing, KVKs play a crucial role in enhancing rural livelihood and self-employment.

2. The Role of KVK in Farmer Empowerment

Krishi Vigyan Kendras (KVKs) play a transformative role in empowering farmers by equipping them with knowledge, skills, and technologies essential for modern, sustainable, and profitable agriculture. Their farmer-centric approach emphasizes **capacity building, technical handholding,** and **linkage facilitation**, enabling farmers to become informed decision-makers and agri-entrepreneurs. Sabira *et.al.* 2016.

Capacity Building Through Training

One of the core functions of KVKs is organizing **skill-based training programs**, both short-term and long-duration, tailored to the local needs and priorities of farmers. These trainings cover a wide spectrum of topics including:

- **Improved Agricultural Practices:** Use of high-yielding varieties, seed treatment, water-saving irrigation techniques, and integrated nutrient and pest management.
- **Integrated Farming Systems (IFS):** Combining crops with livestock, poultry, fishery, or horticulture to optimize resource use and ensure income diversification.
- **Organic and Natural Farming:** Promoting eco-friendly techniques such as composting, biofertilizers, neem-based pest control, and use of cow-based inputs.
- **Dairy, Poultry, and Goat Farming:** Scientific management of livestock for enhanced productivity and income.
- **Agro-processing and Value Addition:** Training on food processing, packaging, branding, and marketing to enhance farm profitability.

Linkage and Institutional Support

KVKs serve as an important link between farmers and key agricultural stakeholders. They coordinate with NABARD, ATMA, ICAR institutes, Krishi Vigyan Kendras, Krishi Vigyan Kosh, and Agri-startups to offer technical, financial, and market-related support. Farmers are also guided to benefit from various government schemes such as PM-Kisan, Soil Health Card, e-NAM, and FPO formations.

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Impact Indicators

The role of KVKs in farmer empowerment is visible through several measurable outcomes:

- Increased adoption of scientific and climate-smart agricultural practices
- Transition from subsistence to commercial and market-oriented farming
- Enhanced crop and livestock productivity and profitability
- Promotion of sustainability through organic and resource-efficient systems

3.Case Studies of Successful Farmers (Crop-Based Interventions)

KVKs have played a pivotal role in transforming the agricultural practices of farmers through timely interventions and personalized technical support. The following crop-based success stories are real-world examples of how scientific knowledge and proper training can bring significant changes in productivity, income, and sustainability. Kumari *et.al.* 2020.

1. Mr. Ramesh Singh (Uttar Pradesh) – Precision Farming in Wheat

Mr. Ramesh Singh, a progressive farmer from eastern Uttar Pradesh, faced challenges with high production costs and stagnant wheat yields. On the recommendation of his district KVK, he attended training on **zero tillage technology, seed treatment**, and the use of the improved wheat variety **HD 2967.**

Through practical demonstrations and field guidance, he adopted zero tillage on 2 hectares of his land. As a result, his wheat yield rose significantly from **36 quintals/ha to 52 quintals/ha**, and he reduced his input cost by approximately ₹4,000 per hectare. The ease of land preparation, fuel savings, and early sowing advantages further boosted his confidence. Motivated by his results, **25 neighboring farmers** in the village also embraced zero tillage, initiating a ripple effect of technology adoption.

2. Mrs. Shanti Devi (Bihar) – Organic Vegetable Farming

Mrs. Shanti Devi, a smallholder woman farmer from Gaya, Bihar, showed remarkable dedication in transitioning from conventional to **organic vegetable cultivation**. She was trained by the local KVK on **vermicomposting, bio-pesticides made from neem,** and **systematic crop rotation** techniques to improve soil health and productivity.

After receiving inputs and handholding support, she converted her half-acre land into a thriving organic farm. Her seasonal income increased from ₹35,000 to ₹85,000. She now sells her produce in local organic markets and weekly haats. Her farm has been **certified as an organic unit,** and she has become a source of inspiration for other women in her panchayat.

3. Mr. Mahesh Patel (Madhya Pradesh) – Pulse Cultivation Under Drought

Mahesh Patel, a rainfed farmer from Sehore, faced frequent crop failures due to drought. With KVK intervention, he adopted a drought-tolerant pigeon pea variety combined with mulching practices demonstrated through a Front Line Demonstration (FLD). The result was impressive: a 20% increase in yield over traditional varieties under limited rainfall. Inspired by his success, 70 farmers in his district adopted mulching and pulse-based cropping systems to enhance resilience.

4.Livestock and Allied Success Stories While crop cultivation forms the core of rural livelihoods, livestock and allied enterprises such as dairy, poultry, and beekeeping are equally vital in ensuring income diversification, food security, and rural employment. KVKs have played a transformative role in promoting these enterprises through targeted training, demonstrations, and convergence with development schemes. Below are a few inspiring stories that highlight how livestock

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and allied sector interventions have improved the lives of small and marginal farmers.

4. Mr. Harinder Singh (Punjab) – Dairy Entrepreneurship

Mr. Harinder Singh, a medium-scale farmer from Ludhiana, Punjab, initially practiced conventional dairy farming with five cows. His productivity remained stagnant due to lack of scientific knowledge and poor animal health management. Upon attending training at **KVK Ludhiana,** he learned about **balanced feeding techniques, mastitis control,** and **hygienic milking practices.**

Implementing these techniques led to a **25% increase in milk yield**. Encouraged by the results, he diversified into value addition by starting a small unit producing **paneer and ghee**. The KVK also helped him get linked with **AMUL** and assisted in availing a **NABARD subsidy** under the Dairy Entrepreneurship Development Scheme (DEDS). Today, he earns over ₹75,000 per month and employs two local youth at his dairy.

5. Mrs. Kusum Bai (Chhattisgarh) – Backyard Poultry Farming

Hailing from a tribal village in Bastar district, Mrs. Kusum Bai had limited livelihood options and used to earn just ₹3,000 a month through seasonal labor. After receiving training from **KVK Jagdalpur** on **Kadaknath poultry breed, brooder house management,** and **vaccination schedules**, she began poultry farming with 100 birds.

Within six months, her **monthly income rose to ₹12,000**, and she expanded her operations by forming a **Self-Help Group (SHG)** of 12 women. Together, they now market poultry meat and eggs locally and have become a model SHG in the region.

6. Mr. Arun Kumar (Odisha) – Beekeeping for Pollination and Income

Mr. Arun Kumar, a marginal farmer from Cuttack, was trained by **KVK Cuttack** in **Apis cerana beekeeping,** hive management, and **honey harvesting**. He started with 10 bee boxes and harvested high-quality honey, earning nearly ₹60,000 in the first year.

Besides monetary gains, he also noticed a **significant increase in mustard yield** on his farm due to better pollination. His success led to the formation of a local beekeeping group, and he now guides other farmers in adopting apiculture as a profitable side enterprise.

5. Integrated Farming System (IFS) and Youth Empowerment

Integrated Farming Systems (IFS) represent a sustainable and efficient approach to farming that ensures optimal use of natural resources and enhances income through diversification. Similarly, empowering rural youth with innovative, high-value agricultural enterprises is vital to make agriculture a profitable and respectable profession. KVKs have been instrumental in promoting both these areas through training, demonstration, and mentorship. The following success stories demonstrate how farmers and youth have embraced new models for agricultural advancement and self-reliance.

7. Mr. Anil Verma (Jharkhand) – Integrated Farming for Self-Reliance

Mr. Anil Verma, a smallholder farmer from Hazaribagh district, Jharkhand, struggled to meet his family's needs with traditional monocropping. Upon engaging with **KVK Hazaribagh**, he was introduced to an **Integrated Farming System (IFS)** model that combined **crop cultivation with fish farming, poultry, and vegetable production.**

He adopted the model on one acre of land, integrating seasonal vegetables with paddy, a small poultry unit, and two fish ponds. This holistic system not only increased his productivity but also ensured round-the-year income. His **net annual income rose to ₹2.5 lakh per acre**, while his dependence on chemical inputs reduced drastically—resulting in a **40%**

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decrease in chemical fertilizer usage. His farm now serves as a training site for other farmers in the block.

8. Miss Renu Yadav (Uttar Pradesh) – Agri-Entrepreneurship in Mushroom Cultivation

Miss Renu Yadav, a graduate from Sultanpur district, was seeking self-employment when she came across a **KVK mushroom training program** in Ayodhya. With technical guidance on **spawn production, compost preparation, and harvesting techniques for button and oyster mushrooms,** she launched a small-scale mushroom unit at home.

Today, she earns a **monthly income of ₹30,000**, supplying fresh mushrooms to hotels, canteens, and local markets. Her initiative not only created employment for two other girls but also received appreciation from the **District Magistrate**, who awarded her for **promoting women-led agri-entrepreneurship.**

9. Mr. Deepak Thakur (Himachal Pradesh) – Horticulture with Drip Irrigation

Mr. Deepak Thakur, an apple grower from Shimla district, modernized his orchard practices after receiving **FLD support from KVK Shimla** on **drip irrigation and fertigation techniques.** By adopting drip irrigation, he significantly improved water-use efficiency—**reducing water usage by 45%**—and enhanced the quality and size of his apples.

With increased profits, he expanded his orchard to **6 acres** and established a small **agritourism unit,** attracting urban visitors and school groups. His model has become a regional inspiration for combining high-tech horticulture with rural tourism.

6. Conclusion, Learnings, and Recommendations

Conclusion:

KVKs are transforming traditional farmers into agri-entrepreneurs. These success stories demonstrate that science-led agriculture combined with training and field support leads to enhanced income, sustainability, and self-reliance.

Key Learnings:

- Tailored training empowers farmers to take better decisions.
- Demonstration and follow-up ensure technology adoption.
- Capacity building of rural women and youth generates employment.

Recommendations:

- Strengthen digital extension through mobile apps and AI tools.
- Promote KVK-led Farmer Producer Organizations (FPOs).
- Increase public-private partnerships for marketing support.
- Expand the outreach of KVKs to remote tribal and hilly areas.

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Silicon and Sulfur: The Next Gen Soil Nutrients for Stronger Vegetables

M. Dhanalakshmi[1] and A. Fahima Fathima[2]

[1] Ph.D. Scholar, Department of Soil Science and Agricultural Chemistrry, TNAU, Coimbatore

[2] Ph.D. Scholar, Department of Vegetable Science, HC & RI, TNAU, Coimbatore

Silicon is available in the form of minerals like feldspar and quartz, is still not considered a necessary for plants. Lately, the accumulation of Si in the form of phytoliths showed that this element is plays an important role as a defensive weapon by coating over plants from herbivory. Similarly sulfur plays a vital role in health, growth and development of plants. It has a plethora of attributes in enhancing crop productivity with a simultaneous robust role in protecting the quality produce. Silicon (as silicic acid or silica) and sulfur are gaining serious traction as next-gen soil nutrients thanks to their unique roles in plant growth, resiliency, yield, and quality. Here's a deep dive into how they work—both separately—to strengthen vegetables:

Silicon: The Structural & Stress Shield

Some of the plants are silicon accumulators (conc. over 1% and [Si]/[Ca] > 1) *viz.,* sugarbeet, tomatoes and some grasses have the ability

a) to resist plant against pests and diseases
b) to resist to drought and saline stressful conditions
c) to tolerate other metal toxicity (As, Cd, Pb, Zn, etc.)
d) to improve nutrient uptake in plants
e) to alleviate phosphorus deficiency in most of the crops

Mode of different experiments/fertilizer forms in vegetables using silicon fertilizers:

Silicon fertilizers can be tested through seed coating, foliar application or by soil application.

1) **Hydroponic experiment:** Vegetables such as cucumber, potato, tomato and sugar beet were studied, especially in hydroponic experiments where nutrients were supplied through nutrient solution. On supplying Si fertilization, improvement in yield and Si accumulation in these vegetables was noticed.
2) **Greenhouse experiment:** Greenhouse/ growth chamber studies had shown that application of amorphous Si fertilizer showed increased productivity in tomato, onion and chili.

Fertilizer forms:

1) **Rice husk biochar (RHB):** Indirect application of Si in brinjal plants through Rice husk biochar (RHB) reduced the insect infestation and also increased the level of Si in the leaves of brinjal.
2) **K_2SiO_3 (Potassium silicate) form:** It was also reported that K_2SiO_3 developed resistance to disease incidence and mildew in tomato plants.
3) **Na_2SiO_3 (Sodium metasilicate) form**: Another study in response to disease occurrence showed that application of Na_2SiO_3 changed the soil microbial properties and increased the seedling growth of cucumber plant thereby it lowered the Fusarium wilt incidence.

Sulfur: The Protein Builder

Over 30% of today's agrochemicals, mostly fungicides, acaricides, and insecticides, contain at least one sulfur atom in different forms.

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(a) It is important for the formation of proteins, amino acids, vitamins, oils and some enzymes.
(b) It plays a vital role in the biosynthesis of some amino acids.
(c) It contributes to the formation of chlorophyll.
(d) It is one of the necessary elements to encourage vegetative growth, increase yield and improve quality.

Effect of sulfur fertilizer in vegetable crops:

Generally crop plants have been classified into three classes (high, medium and low) based on their S requirements where vegetables and cruciferous crops fall under high S requiring species. Some important roles of sulfur are:

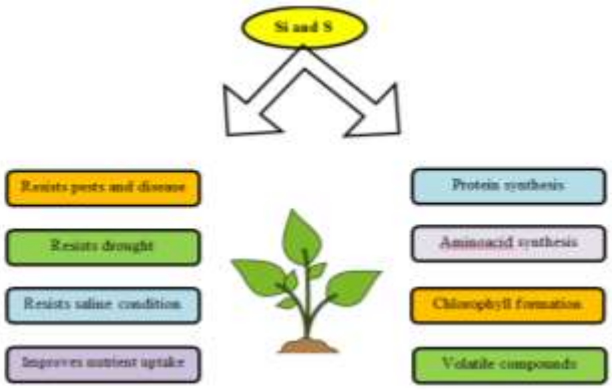
1) Sulphur also plays a crucial role in aiding nitrogen fixation in leguminous plants like clovers, peas, and beans.
2) When comparing the S requirements of crops to phosphorus (P), the typical ratio (P:S) is around 0.6 for cruciferous crops

The growth, yield, and quality effects of S in different crop species have been revealed here,

1) S has shown positive effects on growth, yield and quality in spinach and onion.
2) In another study, testing the response of tropical crops (beans and cabbage) to S, realized yield increases of 8–69% over the control.

Volatile sulfur compounds are often potent odorants, and in many Brassica vegetables, namely broccoli, cabbage, and cauliflower or Allium vegetables *viz*., garlic, leeks, and onions. These compounds play a significant role in the flavor, aroma, and potential health benefits of these vegetables.

S. No.	Volatile compounds	Crops
1.	Allicin, **diallyl sulfide, diallyl disulfide, diallyl trisulfide**	Allium vegetables (garlic, onions)
2.	**Glucosinolates, Isothiocyanates**	Cruciferous Vegetables (e.g., broccoli, cabbage, kale)



Role of Si and S in growth and development of vegetable crops

Summary

Over the years, significant progress has been achieved in Si and S research aimed at explaining the role of these nutrients in increasing yields and improving the nutritional quality of crops. However, significant gaps in our knowledge related to most of these aspects of nutrition remain, like the effect of Nano products on crops or in association of these nutrients with biodegradable polymers for better nutrient availability in soil. In our quest to meet the rising food, animal feed, and biofuel demands for the surging human population, S and Si may play a central role, just like other macronutrients, in sustainable soil fertility management, improving crop productivity and enhancing the production of high nutritive-value crops.

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Commercial Cultivation of Bitter gourd

Amaresh Kumar[1], Gaurav Singh Vishen[2], Sudhir Kumar Mishra[3].
[1]Research Scholar, National Post Graduate College Barhalganj, Gorakhpur
[2]Assistant professor, National Post Graduate College Barhalganj, Gorakhpur
[3]Assistant professor, National Post Graduate College Barhalganj, Gorakhpur

Introduction and importance

Bitter gourd belongs to the Cucurbitaceae family, also known as the gourd family, and is a vine that grows in tropical and subtropical regions, It is Commonly known as bitter melon, balsam pear, or karela, depending on the region.

Medicinal Properties-Bitter gourd has a long history of use in traditional medicine, particularly in Asia, for its potential antidiabetic, anti-inflammatory, and antioxidant effects.

Nutritional Value-It's a good source of vitamins (A and C), minerals (iron, phosphorus), and fiber.

Climate and temperature It is a warm season crop grown mainly in sub-tropical and hot-arid regions. They are susceptible to light frost and are provided with partial protection if grown during winter months. Temperature range of 24°- 27°C is considered as optimum for the growth of the vines. The seed germinates best when temperatures are higher than 18°C. High humidity at the time of vegetative growth renders the crop

Soil:-gourd can be grown on well drained sandy to sandy loam; medium black soils rich in organic matter. Alluvial soil along the river beds is also good for production of bitter gourds. A pH range of 6.0-7.0 is considered as optimum.

Varieties Consumer: -preferences in bitter gourd vary from region to region depending on size, colour, presence or absence of tubercles / ridges and bitterness of fruits. Accordingly a number of varieties are developed in India and details are furnished below

Arka Harit;- IIHR, Bangalore, Fruits short, spindle shaped, green coloured with smooth regular ribs and moderate bitterness. Yield 9-12 t/ha.

Pusa Vishesh;- IARI, New Delhi. Selection from a local collection and suitable for growing during summer. Fruits glossy green medium long and thick.

Pusa Do Mausami:-IARI, New Delhi Fruits dark green, club like with 7-8 continuous ribs. Fruit weight 100-120 g. Yield 12-15 t/ha.

Pusa Hybrid 1:- IARI New Delhi Fruits medium thick, long and gloss green, yield 20 t/ha in 120 days

Kalyanpur Baramasi:- CSAUA &T, Kanpur Fruits long (30-35 cm), light green, thin and tapering, tolerant to fruit fly and mosaic, yield 20 t/ha in 120 days

Coimbatore Long Green:- Extra long fruits (60 cm) with dark green colour.

Coimbatore Long White:-Extra long fruits (60-65 cm) with white colour, yield 15 t/h

Phule Green:- Develop By MPKV agriculture Phule university Maharashtra. Fruit dark green, 25-30 cm long, prickled, tolerant to downy mildew, yield 23n t/ha in 160-180 days

Planting

Land Preparation:- The land is ploughed and brought to a fine tilth by 1-2 crosswise ploughing and levelled. Furrows are opened at a distance of 1.5-2.5 m depending on the support system to be adopted.

Method of Planting: In the plains, the summer season crop is sown from January to February, whereas the rainy season crop is sown in the month of May. For planting one hectare area 4-5 kg of seed is required. Before planting the seed is treated with Thiram (3 g/kg of seed).

Plant support :- Bitter gourd being a weak climber needs support for its growth. The plants trailed on the support (bower) continues to give yield for 6-7 months as against 3-4 months when trailed on the ground without support. Such vines are less susceptible to pest and diseases as they do not come in direct contact with the soil. In bower system, planting is done at a spacing of 2.5 x 1m. Furrows are opened up at 2.5 m and irrigation channels are laid out at 5-6 m distance. Wooden poles (3 m in height) are pitched on both the ends of alternate furrows at a distance of 5 m. these poles are connected with wires.

Manure and fertilizer :- fertilizer doses to be applied depend on variety, fertility of soil, climate and season of planting. Generally well decomposed FYM (15-20 t/ha) is mixed with the soil during ploughing. The recommended dose of fertilizer to be applied per hectare is 50-100 kg N, 40-60 kg P2O5 and 30-60 kg 25 K2O. Half the N and entire P& K should be applied before planting. The balance N is given at the time of flowering. The fertilizer is applied in a ring at 6-7 cm from the base of the stem. It is better to complete all the fertilizer applications just before the fruit set.

Irrigation:- in rainy season crop, irrigation may not be necessary at all, if rainfall is well distributed between July and September. Usually ridges are irrigated a day or two prior to planting of seeds and the next irrigation, preferably light, is given 4 or 5 days after planting of seeds. Subsequently the irrigation is given at weekly intervals. It is necessary to keep the moisture well maintained at the root zone, to promote rapid taproot development.

Intercultural Operations

Weeding:-the crop needs 2-3 weeding operations in order to keep if free from weeds. Normally the first weeding is done 30 days after planting. Subsequent weeding is done at a monthly interval.

Plant growth regulator:- Application of several plant growth regulators like MH (50-150 ppm), CCC (50-100 ppm), Ethrel (150 ppm), silver nitrate (3-4 ppm), boron (3-4 mg/ha) at 2-leaf stage and 4 leaf stage increases the female flowers and yield in bitter gourd. Soaking of seeds with Ethrel or boron (3-4 mg/kg) also increases yield in bitter gourd.

Harvesting:-He crop of bitter gourd takes about 55-60 days from seed sowing to reach first harvest. Further pickings should be done at an interval of 2-3 days as bitter gourd fruits mature very fast and turn red. Picking of fruit at the right edible maturity stage is dependent upon individual kinds and varieties. Normally the picking is mainly done when fruits are still tender and green so that the fruits do not turn yellow or yellowish orange during transport. Harvesting should be done in the morning hours and the fruits should be stored in shade after harvesting.

Yield :-The yield of bitter gourd varies according to the system of cultivation, variety, season and several other factors. The average fruit yield varies from 8 to 10 t/ha.

Hybrid :- 300qt/hec

Seed production:-20-25qt/ hec

Post Harvest Management

Grading : The fruits are graded as per its size and colour. Generally, 20-25 cm long green fruits with short neck and tubercles are preferred.

Packaging : The fruits are packed in bamboo baskets or wooden boxes. Before packing neem leaves or newspaper is spread at the bottom as padding material. Fruits are carefully piled up and covered with gunny bags before sending to the market.

Storage : As the fruits are consumed fresh, they are temporarily stored in shade before packing and transporting.

Diseases.

Powdery Mildew (Sphaerotheca fuligine) : This disease is favoured by high humidity and tends to occur on older leaves first. Symptoms first appear as white powdery residue primarily on the upper leaf surface. On the lower surface of the leaves circular

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patches or spots appear. In severe cases, these spread, coalesce and cover both the surfaces of the leaves and spread also to the petioles, stem, etc. Severely attacked leaves become brown and shrivelled and defoliation may occur. Fruits of the affected plants do not develop fully and remain small.

Control: Carbendazim (1ml/litre of water) or Karathane (0.5 ml/litre of water) is sprayed immediately after the appearance of the disease. 2-3 sprays are taken at an interval of 15 days.

Downy Mildew :Downy mildew is caused by the fungus Pseudoperonosporacubensis. It is prevalent in areas of high humidity, especially when summer rains occur regularly. The disease is first seen as yellow angular spots on the upper surface of the leaves. Under conditions of high humidity, whitish powdery growth appears on the lower surface of the leaves. The disease spreads rapidly killing the plant quickly through rapid defoliation.

Management: Excellent control of this disease can be achieved with Ridomil (1.5 g/litre of water) which must always be used simultaneously with a protectant fungicide such as Mancozeb (0.2%) to prevent the development of resistant strains.

Bitter Gourd Mosaic:-This virus disease is mostly confined to the leaves with symptoms appearing on the leaves in the secondary branches produced at the apical end of the plant. Small irregular yellowish patches are seen on the leaves. Some leaves show vein clearing in one or two lobes of the leaf and severely infected plants show reduction in leaf size and elongation and/or suppression of one or two lobes. Young developing leaves are completely distorted and malformed with considerable reduction in their size. Some of the leaves show marked reduction in the development of lamina resulting in a shoe- string effect. The virus is transmitted by five species of aphids.

Management: -Spraying the crop just after germination with Monocrotophos (0.05%) or Phosphamidon (0.05%) at 10-day intervals prevents aphid vectors.

Source : NHB

Plant Protection

Insect Pests:- Red pumpkin beetle (**Aulacophora foveicollis, A. lewisii**)

Nature of Damage :- Adults feed on the foliage, buds and flowers. Grubs feed on roots. .

Control Measures:- Preventive measures like burning of old creepers, ploughing & harrowing of field after harvest of crop to destroy the stages of pest.

Collection & destruction of beetle in early stage of infestation.

Spraying with 0.05% malathion or dusting with 5% malathion dust @ 10 kg/ha.

Aphids (Aphis gossypii

Nature of Damage : Colonies of nymphs and adults attack leaves and tender shoots and suck the sap; Leaves curl and dry up

Spray 0.02% Pyrethrins or 0.05% Malathion or Dichlorvoe (DDVP

Control Measures: Remove infested leaves and shoots in the initial stage.

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Call for Articles

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