ISSN No: 2583-3146

KRISHI UDYAN DARPAN

(Innovative Sustainable Farming)

Volume 6 I Issue 2 August 2026

SAAHAS

Society for Advancement in Agriculture, Horticulture & Allied Sectors

ISSN No. 2583-3146

Krishi Udyan Darpan

(Innovative Sustainable Farming)

3/2, Drummand Road, (Opp. Nathani Hospital) Prayagraj - 211001 (U.P.)
Mob.- 9452254524
website: saahasindia.org. E-mail.- contact.saahas@gmail.com,
Article Submission:– krishiudyandarpan.en@gmail.com

Editorial Board

❖❖

ISSN No. 2583-3146

Krishi Udyan Darpan

(Innovative Sustainable Farming)

In This Issue

ISSN No. 2583-3146

Impact of Digital Platforms on Agricultural Marketing

Anjna Gupta* and Rashmi Shukla
KrishiVigyan Kendra, Jabalpur

Corresponding Author: blogger.sp2020@gmail.com

Introduction

Agriculture has always been the backbone of many economies, especially in developing countries like India. Traditionally, agricultural marketing involved multiple intermediaries such as traders, wholesalers, and commission agents. This system often led to inefficiencies, lack of transparency, and reduced income for farmers. However, the emergence of digital platforms has significantly transformed agricultural marketing by introducing efficiency, transparency, and direct market access.

Digital platforms-such as e-commerce marketplaces, mobile applications, and online trading systems-have revolutionized how agricultural products are marketed, bought, and sold. These platforms connect farmers directly with consumers, retailers, and exporters, reducing dependency on middlemen and improving profitability. This article explores the impact of digital platforms on agricultural marketing, highlighting their benefits, challenges, and future potential.

Understanding Digital Platforms in Agriculture

Digital platforms in agriculture refer to online systems that facilitate the buying, selling, and exchange of agricultural products and information. These include:

- E-marketplaces (like e-NAM)
- Mobile applications for crop selling and advisory
- Social media platforms for direct marketing
- Supply chain and logistics platforms

These platforms provide farmers with real-time information about market prices, demand trends, and weather conditions, enabling them to make informed decisions. Digital transformation is reshaping agricultural marketing by creating a more integrated and efficient system.

Transformation of Traditional Agricultural Marketing

Before digitalization, farmers relied heavily on local markets (mandis), where prices were often dictated by intermediaries. The lack of transparency and limited bargaining power made farmers vulnerable to exploitation.

Digital platforms have introduced significant changes:

- Elimination of unnecessary intermediaries
- Transparent pricing mechanisms
- Wider market access beyond local regions
- Faster transactions and payments

As a result, agricultural marketing has shifted from a localized system to a more global and interconnected network.

Key Impacts of Digital Platforms

1. Improved Market Access

One of the most important impacts of

digital platforms is improved market access for farmers. Through online marketplaces, farmers can sell their products to buyers across regions and even internationally.

Studies show that digital platforms significantly enhance farmers' access to markets and increase their chances of reaching a larger customer base.

This reduces geographical barriers and allows farmers to explore better price opportunities.

2. Increased Farmer Income

Digital platforms help farmers get better prices by reducing the role of intermediaries. When farmers sell directly to consumers or retailers, they retain a larger share of profits.

Research indicates that the use of digital platforms can lead to increased income levels and reduced transaction costs.

Additionally, digital tools enable farmers to optimize production based on market demand, further improving profitability.

3. Transparency and Price Discovery

Digital platforms provide real-time price information, which helps farmers make better decisions about when and where to sell their produce.

Transparency in pricing reduces the chances of exploitation and ensures fair trade. Farmers can compare prices across different markets and choose the most profitable option.

4. Reduction in Supply Chain Inefficiencies

Traditional agricultural supply chains are often long and inefficient, leading to delays, wastage, and increased costs. Digital platforms streamline these processes by:

- Connecting producers directly with buyers
- Improving logistics and inventory management
- Reducing post-harvest losses

Research shows that digital platforms can significantly reduce logistics costs and improve supply chain efficiency.

5. Empowerment of Smallholder Farmers

Small and marginal farmers often face challenges in accessing markets and information. Digital platforms empower them by providing equal opportunities to participate in the market.

These platforms help bridge economic inequalities by enabling small farmers to compete with larger producers.

6. Data-Driven Decision Making

Digital platforms generate valuable data related to market trends, consumer preferences and pricing patterns. Farmers can use this data to:

- Decide which crops to grow
- Plan production cycles
- Optimize pricing strategies

This shift toward data-driven agriculture enhances efficiency and productivity.

7. Expansion of Digital Marketing Channels

Digital marketing tools such as social media, websites and online advertisements have become essential for promoting agricultural products.

Farmers and agribusinesses can now:

- Build brand identity
- Reach targeted customers
- Promote organic and specialty products

Digital marketing provides a cost-effective and efficient way to expand market reach.

8. Strengthening Farmer-Consumer Relationships

Digital platforms enable direct interaction between farmers and consumers. This helps build trust and transparency in the supply chain.

Consumers can access information about product origin, quality, and production methods, while farmers receive feedback and build customer loyalty.

9. Promotion of Agribusiness and Startups

The rise of digital platforms has led to the growth of agritech startups and innovative business models. These startups provide services such as:

- Online marketplaces
- Supply chain solutions
- Financial services and credit access

Digital marketing also supports the growth of agricultural businesses by increasing visibility and market reach.

10. Integration with Global Markets

Digital platforms enable farmers to connect with international markets, increasing export opportunities. This integration helps farmers earn better prices and improves the competitiveness of agricultural products.

Challenges of Digital Platforms in Agricultural Marketing

Despite their benefits, digital platforms face several challenges:

1. Digital Divide

Not all farmers have equal access to technology. Lack of internet connectivity and digital literacy limits the adoption of digital platforms.

2. Infrastructure Limitations

Poor infrastructure in rural areas, such as unreliable electricity and weak network connectivity, hampers effective use of digital tools.

3. Trust and Awareness Issues

Farmers may hesitate to adopt digital platforms due to lack of trust or awareness. Concerns about online fraud and payment security also exist.

4. High Initial Costs

The cost of smartphones, internet access, and digital tools can be a barrier for small farmers.

5. Policy and Regulatory Challenges

Inadequate policies and lack of proper implementation can hinder the growth of digital platforms in agriculture.

Case Study: Digital Platforms in India

India has made significant progress in digital agricultural marketing through initiatives like e-NAM (National Agriculture Market). This platform integrates various mandis into a unified online marketplace.

Through such initiatives:

- Farmers gain access to nationwide markets
- Price transparency is improved
- Trading becomes more efficient

Digital platforms like mobile apps and agri-tech startups are also playing a crucial role in transforming agricultural marketing in India.

Future Prospects

The future of digital platforms in agricultural marketing looks promising. With advancements in technology such as Artificial Intelligence, Big Data, and Blockchain, agricultural marketing is expected to become more efficient and transparent.

Key future trends include:

- Smart supply chain management
- Predictive analytics for pricing and demand
- Expansion of digital marketplaces
- Increased use of mobile-based platforms

Governments and private sectors must collaborate to ensure inclusive growth and address existing challenges.

Conclusion

Digital platforms have brought a significant transformation in agricultural marketing by improving market access, increasing farmer income, and enhancing transparency. They have reduced the dependency on intermediaries and created a more efficient and connected agricultural ecosystem.

However, challenges such as the digital divide, infrastructure limitations, and lack of awareness must be addressed to fully realize the potential of these platforms. With the right policies, investments, and training programs, digital platforms can play a crucial role in achieving sustainable and inclusive agricultural development.

In conclusion, digital platforms are not just tools for marketing-they are catalysts for change that can reshape the future of agriculture and improve the livelihoods of millions of farmers worldwide.

References

Mathur, A. A., & Shah, B. A. (2025). *Digital Transformation in Agricultural Marketing: Advancing India's Agri-Trade Ecosystem.*

Mishra, A., Raikwar, R. S., & Sharma, K. (2025). *Digital Platforms and E-Marketplaces in Agricultural Marketing.*

Wei, X. (2025). The Impact of *Digital Capability on Agricultural Product Sales.*

Study on Digital Platforms and Market Access (2024–2025).

Rameshkumar, N. (2022). Impact of *Digital Marketing in Agricultural Sector.*

Agriculture Institute (2025). Understanding *Digital Marketing in Agriculture.*

❖❖

ISSN No. 2583-3146

Modern Goat Farming: A Smart Pathway to Sustainable Livelihood

Ruchi Tiwari[1]*, Meena Goswami Awasthi[2] and Vikas Pathak[3]

[1]Department of Veterinary Microbiology, [2&3]Department of Livestock Products Technology U.P. Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go-Anusandhan Sansthan, Mathura, Uttar Pradesh

Corresponding Author: ruchi.tiwari@upvetuniv.edu.in

Introduction

Goat farming has undergone a remarkable transformation in recent decades, evolving from a low-input, subsistence activity into a scientifically managed and economically viable enterprise. In countries like India, where small and marginal farmers dominate the agricultural landscape, goat rearing offers a practical and accessible means of income generation. Its growing relevance is closely linked to rising demand for goat meat, increasing awareness of nutritional security, and the need for sustainable livestock systems that require relatively low investment (Selvam and Murugan, 2026).

Unlike large ruminants, goats are highly adaptable and resilient animals. They can survive and produce under a wide range of environmental conditions, including arid, semi-arid, and hilly regions. Their browsing habit allows them to utilize shrubs, bushes, and crop residues that are often unsuitable for other livestock. This unique ability makes goats particularly valuable in resource-poor settings, where feed availability is limited. Additionally, their smaller body size and ease of handling make them suitable for women and elderly farmers, thereby contributing to inclusive rural development.

Scientific Approach in Modern Goat Farming

Modern goat farming is characterized by the adoption of improved and scientific management practices that enhance productivity and reduce risks. One of the first steps in establishing a successful goat enterprise is the selection of appropriate breeds. Farmers are increasingly focusing on selecting disease-resistant and climate-resilient breeds to ensure sustainability under changing environmental conditions. Crossbreeding programs are also being adopted in some regions to combine desirable traits such as higher milk yield, faster growth rate, and better reproductive performance, thereby improving overall farm profitability. Farmers now make informed choices based on production goals such as milk, meat, or dual-purpose utility. Indigenous breeds like Jamunapari, Beetal, and Black Bengal have gained prominence due to their adaptability and performance under Indian conditions. Popular goat breeds and their production characteristics are presented in Table 1.

Table 1: Popular Goat Breeds and Their Utility

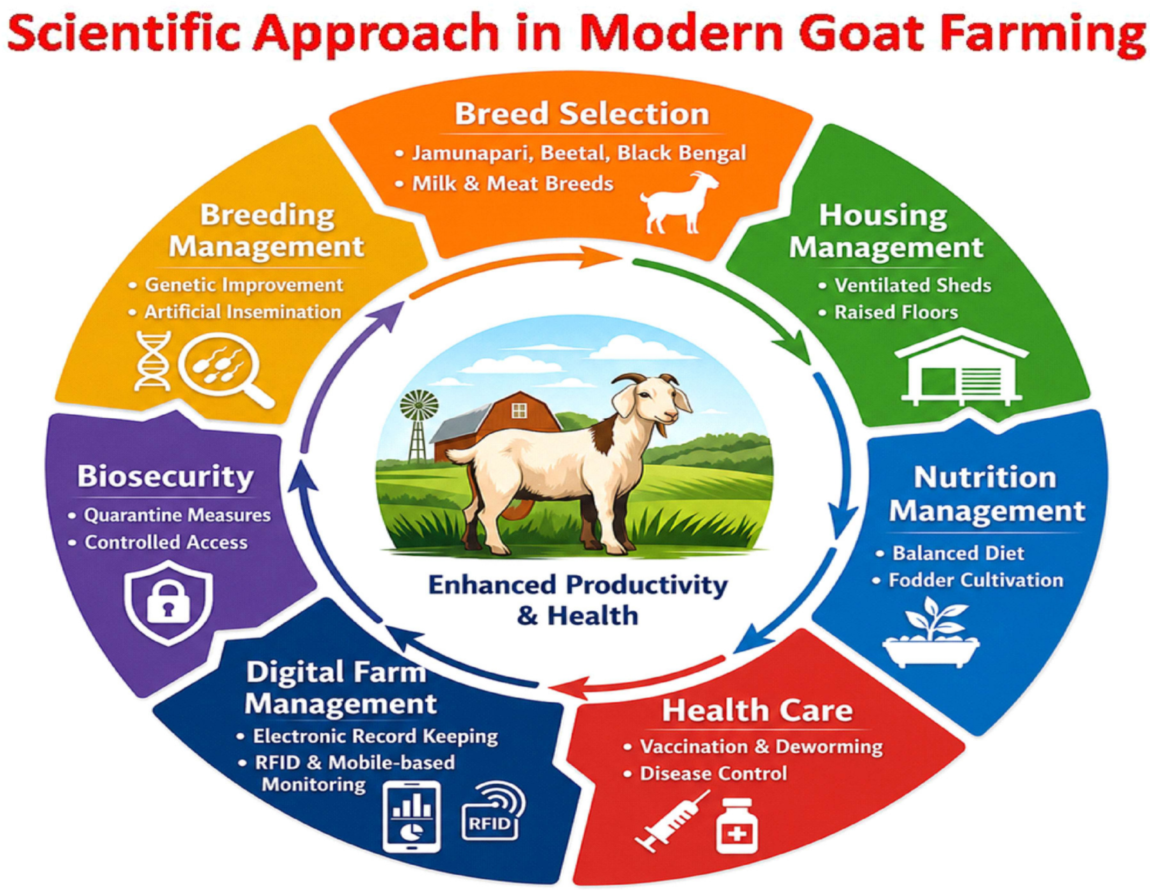
Breed Name	Primary Purpose	Key Characteristics	Average Performance
Jamunapari	Milk & Meat	Large body size, high milk potential	2–3 litres milk/day
Beetal	Milk & Meat production	Good adaptability, consistent	1.5–2.5 litres milk/day
Barbari	Meat	Early maturity, prolific breeder	20–25 kg body weight
Black Bengal	Meat	High fertility, superior meat quality	15–20 kg body weight
Sirohi	Meat	Hardy, suited for arid conditions	25–30 kg body weight

Housing management has also seen significant improvements. Traditional open systems are gradually being replaced by well-designed sheds that ensure proper ventilation, hygiene, and protection from extreme weather. Raised or slatted floor housing is becoming increasingly popular, as it helps maintain cleanliness and reduces disease incidence by preventing direct contact with waste.

Nutrition plays a central role in determining the productivity of goats. Nutritional deficiencies and metabolic disorders like pregnancy toxemia, milk fever, and mineral deficiencies can further compromise animal health and performance. Therefore, Modern feeding practices emphasize a balanced diet consisting of green fodder, dry roughage, and concentrate feed, along with essential mineral supplements. Strategic feeding not only improves growth rates and milk yield but also enhances reproductive efficiency. Farmers are also being encouraged to cultivate fodder crops and adopt stall-feeding practices to ensure consistent nutrition throughout the year.

Health care management is another critical component of scientific goat farming. Preventive measures such as regular vaccination, timely deworming, and routine health check-ups are essential to control common diseases like Peste des Petits Ruminants (PPR) and Foot and Mouth Disease (FMD). In addition to these, farmers must remain vigilant against other important infectious and parasitic diseases such as Goat Pox, Enterotoxaemia, Hemorrhagic Septicemia, Contagious Caprine Pleuropneumonia (CCPP), Bluetongue, Brucellosis, Johne's disease, Caseous Lymphadenitis and Mastitis. Parasitic infestations including gastrointestinal nematodes, coccidiosis, lice and mites (mange) also significantly affect productivity if not managed properly. With increasing awareness, farmers are now more inclined to adopt biosecurity measures by following controlled farm access, sanitation and quarantine of new animals to safeguard their herds.

Breeding management has also shifted toward planned and controlled practices. Selection of superior breeding males, avoidance of inbreeding, and culling of unproductive animals contribute to gradual genetic improvement. In some organized farms, advanced techniques such as artificial insemination are also being explored. Maintaining proper records of breeding, growth, and health has become an integral part of modern farm management, enabling data-driven decision-making.



Economic Significance and Benefits

The economic advantages of goat farming make it an attractive enterprise for both rural and peri-urban populations. One of its biggest strengths is the relatively low capital requirement compared to other livestock ventures. Farmers can start with a small herd and gradually expand based on available resources and market demand. The short gestation period and higher kidding rates ensure quicker multiplication of stock, leading to faster returns on investment.

Goat meat enjoys widespread acceptance across different cultural and religious communities, ensuring a stable and high-demand market. In addition to meat, goat milk is valued for its nutritional and medicinal properties, while goat manure serves as an excellent organic fertilizer, contributing to soil health and crop productivity.

Furthermore, goat farming generates employment opportunities along the value chain, including breeding, feed supply, processing, and marketing. It also plays a significant role in empowering women, as goat rearing is often managed at the household level.

Challenges and the Way Forward

Despite its potential, modern goat farming is not without challenges. Limited access to high-quality breeding stock, inadequate veterinary infrastructure, and occasional disease outbreaks can affect productivity. Market fluctuations and lack of organized marketing channels may also reduce profitability for small farmers.

To overcome these constraints, there is a need for strengthened extension services, farmer training programs, and better access to credit and insurance facilities. Formation of cooperatives and farmer producer organizations can help in improving market access and ensuring fair prices. Adoption of digital tools and mobile-based advisory services can further support farmers in making timely and informed decisions.

Future Prospects

The future of goat farming appears highly promising, particularly in the context of sustainable and climate-resilient agriculture. As consumers increasingly prefer organic and naturally produced food, goat products are gaining greater acceptance. Integration of goat farming with crop production, agroforestry, and other livestock enterprises can create a diversified and resilient farming system.

With continued support from research institutions, government initiatives, and market innovations, goat farming has the potential to significantly enhance rural livelihoods and contribute to the agricultural economy.

Conclusion

Modern goat farming represents a harmonious blend of traditional wisdom and scientific innovation. It offers a practical solution to many of the challenges faced by small-scale farmers, including limited resources and uncertain income. By adopting improved management practices and focusing on market-oriented production, farmers can transform goat rearing into a sustainable and profitable enterprise. In the years to come, goat farming is likely to play an increasingly important role in ensuring food security, generating employment, and promoting rural prosperity.

References

C. Devendra, M. Burns. Goat production in the tropics. Commonwealth Agricultural Bureaux, Farnham Royal, UK (1983).

Indian Council of Agricultural Research (ICAR). Handbook of animal husbandry. ICAR Publications, New Delhi, India (2022).

Government of India. Basic animal husbandry statistics. Ministry of Fisheries, Animal Husbandry & Dairying, New Delhi, India (2023).

Food and Agriculture Organization (FAO). Small ruminant production and health guidelines. FAO Animal Production Series, Rome, Italy (2021).

C. Peacock. Goat development for sustainable livelihoods. Farm-Africa, London, UK (2005).

N. Singh, B. Rai, R. Singh. Advances in goat farming practices in India. Indian J. Anim. Sci., 88 (2018), pp. 365–372.

Selvam, R., & Murugan, M. (2026). Integrated Goat Production Systems in India: Strategies for Genetic Improvement and Sustainable Livelihoods. Archives of Current Research International, 26, 173–186.

ISSN No. 2583-3146

Science Meets the Soil: The Viksit Krishi Sankalp Abhiyan and the Promise of a Prosperous Northeast

How a Nationwide Agricultural Campaign is Planting the Seeds of Viksit Bharat 2047 in India's Green Hills

P. K. Pathak[1*], A.K. Mohanty[2], Anmol Giri[3], A.K. Singha[4], Amrutha T.[5] , Divya Parisa[6] and Mainak Ghosh[7]

[1]Department of Livestock Production and Management, [2&4]Department of Extension Education, [3&5]Department of Agricultural Economics, [6]Department of Horticulture, [7]Department of Agronomy

ICAR- Agricultural Technology Application Research Institute Zone-VII, Umiam, Meghalaya

Corresponding Author: drpkp19@gmail.com

Introduction

When the paddy fields of Manipur were submerged under flood waters and the hillsides of Mizoram lay scarred by landslides, something remarkable happened. Scientists, extension workers, and farmers refused to give up. They rerouted their paths, rescheduled their meetings, and found ways to reach one another. That determination, replicated across five states of India's Northeast, is the defining spirit of the Viksit Krishi Sankalp Abhiyan, a campaign that may quietly turn out to be one of the most consequential outreach efforts in the history of Indian agriculture.

A Nation's Vision, A Region's Opportunity

India is marching towards a grand transformation. The Viksit Bharat 2047 vision anchored in the Prime Minister's call for a developed, self-reliant, and equitable India by the centenary of Independence places agriculture at the very heart of national progress. For a country where nearly half the workforce is still engaged in farming, and for a region like the Northeast where farming is not just livelihood but identity and culture, this vision carries special weight.

The North-Eastern states of Meghalaya, Manipur, Mizoram, Nagaland and Tripura together span a geographical area of 92.6 lakh hectares. They are home to over 131 lakh people, of whom more than 27 lakhs are farm families. The region sits within the Eastern Himalayan biodiversity hotspot, one of only 36 such globally recognised zones. Its hills and valleys nurture crops, plants, and farming traditions found nowhere else on earth. Yet for decades, this agricultural wealth has remained underexploited, held back by poor connectivity, acidic soils, a monsoon that can be a friend and a destroyer in the same season, and a persistent gap between what research institutions know and what farmers actually practise.

It was precisely to bridge this gap that the Union Minister of Agriculture and Farmers' Welfare launched the Viksit Krishi Sankalp Abhiyan (VKSA) on 29 May 2025. Implemented across more than 700 districts of India and running until 12 July 2025, the campaign deployed over 2,170 teams nationwide, ultimately reaching more than 1.35 crore farmers. In the Northeast alone, under ICAR-ATARI Zone VII headquartered at Umiam in Meghalaya, the campaign became an extraordinary meeting of minds, monsoons, and muddy boots.

The Northeast's Agricultural Reality

To understand why the VKSA matters so deeply for the Northeast, one must first appreciate the complex canvas on which farming here is painted. The five states under ICAR-ATARI, Zone VII each have their own agro-climatic character. Meghalaya, home to Cherrapunji and Mawsynram, two of the wettest places on Earth receives annual rainfall that can exceed 11,000 mm in some pockets. Its soils are strongly acidic, with pH values often below 5.0, making nutrient management a perpetual challenge. Yet the same conditions that make farming difficult also foster extraordinary biodiversity: from pineapples and jackfruit in the foothills to pears and plums in the highlands of the Khasi Hills.

Manipur's valley lands are fertile, but its hill districts carry the burden of acidic red soils and seasonal isolation. Mizoram, where nearly 90 percent of the land is hilly, practises a mix of lowland paddy cultivation and jhum, or shifting cultivation, a tradition embedded in tribal culture but one that increasingly conflicts with soil conservation goals. Nagaland, with rainfall ranging from 2,000 to 3,000 mm annually, grows paddy on terraced hillsides that have been carefully sculpted over generations. Tripura, the most densely populated of the five at 415 persons per square kilometre, is better connected to the mainland and has emerged as a strong performer in the region's agricultural economy. Across all five states, rice and maize form the backbone of Kharif cultivation, supplemented by pulses, oilseeds, a magnificent array of horticultural crops, and increasingly important animal husbandry and fisheries sectors.

Yet productivity lags national averages. The reasons are structural: small and scattered landholdings that defy mechanisation, limited access to quality seeds and organic inputs, inadequate cold storage and market infrastructure, poor veterinary coverage, and the ever-present threat of African Swine Fever ravaging pig populations across tribal households. Climate change has added another layer of uncertainty, with erratic rainfall patterns disrupting traditional sowing calendars.

A Campaign Takes Shape

The ICAR-ATARI, Zone VII mounted a logistically sophisticated response to this complex agricultural landscape. An extensive network of institutions were mobilised: 43 Krishi Vigyan Kendras (KVKs) spread across all five states, scientists from ICAR-Research Complex NEH Region and its regional centres, faculty from nine constituent colleges of Central Agricultural University, researchers from Nagaland University, and the dedicated College of Agriculture, Tripura. Altogether, 477 scientists participated, supported by over 300 officials from state agriculture and allied departments.

Each district was assigned three teams per day. Each team was tasked with visiting three villages and engaging at least 400 farmers during each visit. These were not passive information sessions. Teams carried seed packets, distributed literature in local languages, conducted demonstrations, and crucially listened. They noted what farmers were struggling with, what innovations they had independently developed, what germplasms existed in surrounding forests, and what they wished researchers would prioritise. This two-way character of the campaign was arguably its most transformative feature.

Against a target of covering 4,632 villages and reaching 6,19,200 farmers, the Zone VII teams ultimately covered 4,997 villages nearly 108 percent of the target and engaged 574,991 farmers. That nearly 93 percent of the farmer target was achieved despite unprecedented climatic chaos speaks to the commitment of everyone involved. The campaign was conducted over just twelve effective working days, a constraint imposed by public holidays, tribal observances, and the sheer scale of natural disruptions during those weeks.

When Nature Pushed Back

The days between 29 May and 12 June 2025 were not kind to the Northeast. In Nagaland, landslides blocked National Highway 29, claimed six lives, and left communities isolated. Manipur saw extensive flooding across Imphal East, Imphal West, and Senapati districts, with bridges washed out and roads submerged. In Mizoram, a quarry collapse in Aizawl triggered by torrential rain killed fourteen people and the state administration ordered a complete suspension of the cam-paign from 1 to 3 June. Meghalaya experie-nced multiple landslides, while Tripura saw statewide flooding that inundated vast stretches of agricultural land.

State governments responded with a cascade of disaster management notifications, travel advisories, school closures, red alerts, and emergency orders that constrained movement across all five states. Undeterred, KVK teams rescheduled missed visits, compressed itineraries, reached out through phone and social media when physical access was impossible, and resumed operations the moment conditions allowed. The result was that even Mizoram, which lost three campaign days entirely, still reached 67,222 farmers across 626 villages.

Tripura stood apart in this story of resilience. Blessed with relatively better road connectivity and galvanised by the personal involvement of Hon'ble Chief Minister Dr. Manik Saha and Agriculture Minister Shri Ratan Lal Nath, the state's teams exceeded their village target by ten percent and surpassed their farmer target by an astonishing 77 percent, reaching over 2,04,000 farmers across all eight districts. The scale of participation in West Tripura alone, where 36,445 farmers were engaged across 179 villages, is a testament to what organised, policy-backed outreach can achieve.

The Science That Reached the Farm

What did these teams carry with them to the fields and village squares of the Northeast? The content of the campaign was carefully tailored to the Kharif season, the primary agricultural window for the region. For paddy farmers in Manipur, scientists recommended disease-resistant and high-yielding varieties like RC Maniphou-13, 14, 15 and 16, along with guidance on seed treatment with Trichode-rma and integrated pest management using biological agents like Trichogramma. For maize growers, composite varieties such as RCM-75 and hybrids like Vivek QPM were promoted, with detailed guidance on managing the devastating Fall Armyworm that has swept through the Northeast in recent years.

Meghalayan farmers received advisories on paddy varieties suited to the state's acidic soils and heavy rainfall, including Megha SA-2, CAU-R1, and CR Dhan-310 and 311. Ginger and turmeric growers were advised on rhizome treatment with biocontrol agents to prevent soft rot, a disease that can destroy an entire crop. In Mizoram, guidance on upland paddy cultivation using drought-tolerant varieties developed specifically for the state's jhum systems was provided, along with advice on SRI, the System of Rice Intensification that can dramatically improve yields while conserving seeds and water. Nagaland's farmers received detailed advisories on large cardamom management, millet cultivation using local varieties like Shongtak and Langjai, and the management of Naga King Chilli, one of the world's hottest and most commercially valuable peppers.

Beyond crops, the campaign addressed livestock and fisheries with equal seriousness. Piggery advisories covered biosecurity protocols for African Swine Fever, deworming schedules, breed selection, and farrowing management, all critical for the pig-dependent tribal farming households of the region. Poultry guidance promoted improved breeds like Vanaraja and Kuroiler for backyard rearing. Fisheries advisories addressed pond preparation, stocking densities, fingerling production, and the use of locally available feed resources like rice bran and mustard oil cake. Mithun, the unique semi-wild bovine of the Northeast, central to the culture and economy of Nagaland and Arunachal Pradesh received special attention, with guidance on concentrate feeding, mineral supplementation, deworming, and FMD vaccination.

All this was accompanied by information on government schemes like PMFBY, PM-Kisan Samman Nidhi, PMMSY, Soil Health Cards, FPO formation, and the Natural Farming Mission that many farm families were either unaware of or unable to access due to procedural barriers. The campaign served as a crucial bridge, linking policy intent with farm-level reality.

Listening as Much as Teaching

Perhaps the most enduring contribution of the VKSA was not what scientists told farmers, but what farmers told scientists. The structured field interactions surfaced a rich inventory of local knowledge, urgent research needs, and genuine innovations. The region's biodiversity is legendary, and the campaign documented unique germplasms that deserve formal scientific attention and conservation. In Meghalaya, wild fruits like Sohphie (Myrica esculenta) and Sohiong (Prunus nepalensis) were identified as having significant commercial potential for wine, jam, and nutraceutical production. In Nagaland, forest fruits like Rambutan, Fragrant Caper Vine, Bay Berry, and Cane Fruit were documented, each carrying nutritional and medicinal properties known to local communities for generations. Mizoram contributed the Windmill Palm (Trachycarpus Fortune) with its antioxidant and cardiovascular benefits, as well as the Tawkte (Solanum violaceum), used in folk medicine for treating wounds, jaundice, and high blood pressure. Tripura documented the Bilati Begun (Solarium torvum Swartz), a tribal food plant with notable nutritional compounds. These are not museum specimens, they are living resources that with appropriate research and value chain development, could become significant commercial crops and nutrition sources for local communities.

Farmer innovations documented during the campaign offer equally exciting possibilities. D. Pyrtuh of Meghalaya, an illiterate farmer, has developed a technique of raising paddy nurseries in bamboo splits an elegant, low-cost solution to nursery preparation on difficult terrain. A farmer in Nagaland's Phek district has designed a low-cost drum-type paddy thresher suited to small farmers, while another has created a bamboo-based potato storage model. From Manipur came an innovative zero-energy water-lifting device, and a creative use of agricultural lime to control brown leaf hopper in rice. A farmer in Mizoram uses palm oil cake as fish feed, and a Meghalaya farmer has devised a bamboo-based drip irrigation system for fruit crops. Taken together, these innovations represent a grassroots engineering tradition that formal research institutions would do well to study, validate, and scale.

The Indigenous Technical Knowledge (ITK) documented during the campaign is equally rich. Farmers use garlic extract to manage pests in vegetables, ash broadcasts in paddy fields to control insects, tobacco mixed with salt to repel slugs, rotten crab filtrate as a natural pest repellent, walnut leaf juice for fish harvesting and controlling poultry lice, and wood ash for seed storage in pulse crops. A farmer in Nagaland uses Sumac powder to treat diarrhea in pigs. These practices, rooted in ecological observation and centuries of experience, deserve scientific validation and integration into formal extension packages.

What the Fields Are Asking For

The VKSA also revealed uncomfortable truths. There is no vaccine available anywhere in the world for African Swine Fever, and the campaign made clear that this remains an existential threat to pig farming across all five NEH states. High-yielding sticky rice varieties suited to local taste preferences in Mizoram and Meghalaya remain unavailable from formal research systems. Organic herbicides suitable for jhum farming systems which require selective weed control without harming a diverse array of mixed crops simply do not exist in the research pipeline. Farm machinery designed for steep slopes and small landholdings is absent from most equipment catalogues. Post-harvest technology for indigenous fruits, which currently rot within days of harvest, remains rudimentary. Veterinary coverage in remote tribal areas is desperately thin.

These are not complaints without solutions. They are researchable problems, with clearly defined contexts and communities willing to collaborate. The VKSA's greatest achievement may be that it has provided ICAR and its partner institutions with a detailed, ground-truthed research agenda for the Northeast, one that reflects what farmers actually need rather than what researchers assume they need.

Women at the Centre

One of the most striking aspects of the VKSA data is the prominent participation of women farmers. In Meghalaya, over 64 percent of the farmers reached were women, 55,076 out of 85,231 a reflection of the Khasi and Jaintia matrilineal traditions where women are central to both household and land management. In Jaintia Hills district alone, nearly 74 percent of participants were women. Across the zone, 250,719 women farmers out of a total of 574,991 participated, accounting for nearly 44 percent of total outreach.

This is not merely a demographic footnote. Women in the Northeast are primary practitioners of subsistence agriculture, livestock rearing, and food processing. Their access to scientific knowledge, high-quality inputs, and government schemes has historically been limited. The VKSA created rare and valuable space for these conversations. Extension programmes going forward must be designed with this participation in mind, ensuring that technology packages, training, and instituti-onal linkages are explicitly targeted at women farm operators.

Building Towards 2047

The Viksit Bharat 2047 mission envisions an India where no citizen is left behind, where the fruits of development reach every village and every household. For that vision to become reality in the Northeast, agriculture must be transformed: from subsistence to sufficiency, from isolation to integration, from tradition alone to tradition enriched by science.

The VKSA is a step in that direction. But one step is not the journey. The insights gathered during those twelve intense days in May and June 2025 must now be converted into action. Researchable issues identified by farmers must enter the work-plans of ICAR institutes and State Agricultural Universities. Indigenous innovations must be validated and disseminated through KVK networks. Unique germplasms must be conserved and studied. Farmer training programmes must address the knowledge gaps documented - in protected cultivation, scientific nursery management, post-harvest technology, artificial insemination, fisheries seed production, and natural farming.

Infrastructure investments are equally urgent. Cold storage, market linkages, and processing facilities for horticultural produce must be developed to prevent the distress sales that currently erode farmer incomes. Real-time disease surveillance systems with GIS mapping, as requested by farmers in Tripura for livestock diseases, must be operationalised. Credit and insurance schemes must be made more accessible to tribal communities operating under customary land tenure systems that formal financial institutions struggle to recognise. The media coverage generated by the campaign 93 press articles, 38 television and radio segments, and over 1,396 social media posts across five states has created a foundation of public awareness. That awareness must now be sustained through consistent communication, celebrating farm successes, sharing research findings in local languages, and keeping the conversation between scientists and farmers alive well beyond the campaign fortnight.

A Final Word

The Northeast of India is often spoken of in terms of its challenges: remoteness, difficult terrain, ethnic complexity, and developmental lag. The Viksit Krishi Sankalp Abhiyan offers a different lens. It reveals a region of extraordinary ecological wealth of farmers who are not passive recipients of outside knowledge but active innovators of communities that have sustained agriculture on steep hillsides with minimal external support for generations, and of scientists and extension workers capable of remarkable dedication when given clear purpose and institutional backing.

The 5,74,991 farmers who participated in the VKSA across Meghalaya, Manipur, Mizoram, Nagaland and Tripura are not statistics. They are smallholder families for whom better seeds, timely advice, fair markets and adequate infrastructure can mean the difference between a child going to school or staying home, between food security and hunger, between staying on the land and migrating to a city. The Viksit Bharat 2047 mission will be measured, ultimately, by whether it reaches them. The VKSA has shown that it can be done even in monsoon, even through a landslide, even on the far side of a washed-out bridge. What it requires is science, sincerity, and the willingness to listen.

Source: Technical Report on Viksit Krishi Sankalp Abhiyan (29th May – 12th June 2025), ICAR-Agricultural Technology Application Research Institute, Zone VII, Umiam, Meghalaya.

❖❖

ISSN No. 2583-3146

Sowing Method

Garima Kaushik Parashar* and Himanshu Rawat
Department of Agriculture, GRD Institute of Management & Technology, Dehradun
Corresponding Author: garimakaushik1991@gmail.com

Introduction

Agriculture is the backbone of Indian Economy. Sowing is one of the fundamental agronomic operations. Different sowing methods have been developed based on crop requirement, soil characteristics, climatic condition and mechanization levels. It plays a crucial role in determining seed distribution, planting depth, plant population, nutrient utilization and overall crop productivity. Scientifically planned sowing ensures optimum soil- seed contact, adequate moisture availability and proper aeration which are essential factor for successful seed germination and vigorous seedling growth. Proper sowing techniques help achieve uniform crop stand, reduce seed losses, improve input-use efficiency and facilitate intercultural operation such as irrigation, weeding and harvesting. Modern agriculture emphasizes precision sowing methods to enhance productivity and profitability.

Sowing

Sowingis the process of placing the seed in the ground with proper depth to grow into a new plant.

Transplanting

It is the method in which seedlings, first which raised in the nursery for proper growth and development and then transplanted in the main field for further growth.

Propagation

It is the method by which new plants are raised with the different plant parts ie, seedlings, roots, tuber, leaves or cutting.

Different types of Sowing Method

- Broadcasting
- Drilling
- Dibbling
- Behind the plough
- Furrow sowing
- Line sowing
- Bed plantation
- Pit plantation
- Transplanting

Broadcasting

It is the most common and oldest method of seed sowing. It includes scattering of seed with hand to the well-prepared field and covered the seed with the help of wooden planker. This method is not suitable as it causes wastage of seeds.

Advantage

- This method is only suitable for small seeded crops, where plant to plant distance is small or does not even matter.
- Tillage implements not required.
- Skilled labor not required.
- Cheapest and quickest method of sowing.
- Required moist condition.

Disadvantage

- No proper spacing is required.
- More wastage of seed.
- No uniform crop stand.
- If adequate moisture is not available in the soil gappy germination takes place.

Drilling or Line sowing

It is the method of sowing in which sowing is done with the help of tools and implements such as seed drill, seed cum ferti driller or mechanical seed drill the seeds are covered with soil by wooden planker to have good contact between seed and soil. Rows can be made according to the seed size or crop. Eg- Jowar, wheat, bajra are the different crops sown by this method.

Advantage

- Proper moisture is necessary during sowing.
- In this method of sowing seed requirement is less as compare to broadcasting method.
- Proper row to row distance is well maintained for good crop stand.
- By this method, rapid germination and good plant stand can be maintained.
- Depth of sowing is maintained according to seed size.

Disadvantages

- Skilled labor is required for this method.
- Plant to plant distance not required.
- Tools and implements used in this method is quite costly.
- Proper moisture during sowing is must.

Dibbling

It is the method of sowing seeds in which seeds are placed in the holes or pits manually or by dibbler or planter. Eg: cotton, castor, groundnut etc. are the crops grown by this method.

Advantage

- Row to row and plant to plant distance should be maintained.
- It can be done manually or with dibbler.
- As compare to other methods seed requirement is less.
- Intercultural operations can be done easily.
- Optimum plant population can be maintained.

Disadvantage

- Increase cost of cultivation as it requires more labor.
- More laborious and time-consuming method of sowing.
- Bold sized seeds are sown.
- Required strict supervision.

Transplanting

It is the method of planting in which seedings are first raised in a nursery bed for proper care and maintenance and when they attain suitable growth, they are then transplanted to the well-prepared main field for subsequent growth and development. Seedlings are allowed to grow in the nursery bed for about 3-5 weeks. Before transplanting in the main field, the field are watered properly one day before to prevent the jerk to the roots of the plants. Eg: Paddy, tobacco, vegetables, fruits etc.

Planting

It is the placing of planting materials including seed, seedlings, tubers, cutting, roots etc into the soil for crop production. Eg: potato, ginger, turmeric, sets of sugarcane etc.

Behind the plough

In this method seeds are dropped manually in the furrow which is prepared by the plough with the help of labor by hand and then covered it with soil. Eg: Gram. This method is not commonly followed for sowing.

Advantages

- This method is simple and not very costly.
- Faster than dibbling method.
- Suitable for both medium and large seeded crops.
- Less tools and equipments are required

Disadvantage

- No uniform seed distribution.
- Seed wastage is comparatively high.

- For manual dropping of seeds more labor is required.
- Not recommended for precision farming.

Ring pit method

It is the method of planting of sugarcane and fruit plants in which ring pits are prepared and planting material are planted inside them with proper spacing and depth. It is commonly used in sugarcane (technique is developed by university of Agriculture faislabad) sugarcane is planted in 100x100 cm pits, 50 cm apart with a seedling density of 30 two budded setts per pits, instead of standard 90cm apart double row strip planting system with a planting density of about 10 two buded setts per square meter.

Advantage

- Higher yield of sugarcane as well as for ratoon crop.
- Due to localized placement nutrient use efficiency can be enhanced.
- Generate employment opportunity.
- Required less irrigation.

Disadvantage

- Non availability of ring pit digger machine
- For Manual pit making more labor is required.
- Not suitable for all soil types.
- High initial cost.
- Required skilled labor for pit preparation.

Furrow Method

It is the method of planting and irrigation in which crops are sown in rows along the furrow (small channels). To irrigate the crop water flows through the furrows.

Advantage

- Waterlogging condition is reduced.
- In saline soils furrow provide better germination.
- Mainly suitable for row crops like sugarcane, potatoes.
- Intercultural operations will easily be done
- Provide proper moisture to root zone.

Disadvantage

- Manual sowing is difficult in this method
- More labor is required.
- More expensive method.
- Bed and furrow shaper is expensive to buy
- Proper land levelling is required.
- Not suitable for all soil types.

Most common and efficient method

Among all the different methods of sowing, seed drill method is considered the most efficient and widely used modern method. It is most efficient because of the following reasons:

- Uniform distribution of seeds.
- Proper depth and spacing which helps better germination and healthy plant growth.
- No wastage of seeds.
- Better utilization of water and fertilizers.
- Easy weed control and harvesting.
- High crop yield, as plants get enough sunlight, nutrients and air.
- Save time and labor.

Conclusion

Method of sowing is a critical factor in successful crop production, as it directly influences seed germination, plant establishment, crop growth and final yield. Scientific and appropriate sowing techniques ensure uniform seed placement, optimum plant population, efficient utilization of soil moisture and nutrients and better management of agricultural operations. Selection of a suitable sowing method according to crop type, soil condition, climate and available resources enhances productivity and promote sustainable agriculture. Therefore, proper sowing practices are essential for achieving higher agricultural efficiency and improved crop performance.

❖❖

ISSN No. 2583-3146

Role of Plant Growth Regulators in Fruit Crops

Preetika Verma[1*], Naveen Chand Sharma[2] and Mohit[3]

[1&2]Department of Fruit Science, COH, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh

[3]Department of Soil Science, COA, CSKHPKV, Palampur, Himachal Pradesh

Corresponding Author: preetika7007@gmail.com

Introduction

Plant growth regulators (PGRs) or phytohormones are organic compounds, other than nutrients, that produced naturally in higher plants, controlling growth or other physiological functions at a site remote from its place of production and active in minute amounts, modify plant physiological process. PGRs called biostimulants or bioinhibitors, act inside plant cells to stimulate or inhibit specific enzymes or enzymes systems and help regulate plant metabolism. They normally are active at very low concentrations in plants. Plant growth regulators generally included Auxins, cytokinins, gibberellins, abscisic acid and ethylene are the five classical, naturally occurring PGRs. More recently, several other compounds have been discovered with biological activity which equals to or exceeds that of the equivalent endogenous PGRs. These include: polyamines, brassinosteroids, jasmonates, salicylic acid, signal peptides, oligosaccharides, sterols and systemins. They have definite regulatory roles in the growth and development of plants.

Advances in use of plant growth regulators in fruit crops production

1. Seed germination: Seed germination may require gibberellins for the activation of vegetative growth of the embryo. Gibberellin application also activates the alpha amylase synthesis in the aleurone layer where it converts starch to sugar which translocated to growing embryo to provide energy source.

Pre-sowing treatment with GA_3 at 200 ppm was found effective in increasing germination and extending seed longevity of ber cv. Gola. Incidence of polyembryony was highest with 400 ppm GA_3 and 1000 ppm Cycocel (Hore and Sen, 1994).

2. Control of vigour: Various growth retardants have been used to restrict the vegetative growth of plant such as AMO 1618, ancymidal, pacloburazol, B-9 (Phosphon D), chlormequat etc. The reduction in vegetative growth by growth retardants is due to the systemic inhibition of GAs biosynthesis pathway at the sub-apical meristem, which ultimately reduced cell elongation and rate of cell division and decreased the shoot growth. These growth retardants also inhibit the gibberellin precursor by blocking the oxidation of entkaurene to ent-kaurenoic acid.

- A class of inhibitors of gibberellins biosynthesis, the cyclohexanetriones has the ability to control the vegetative growth. This class includes the Prohexadione calcium (PCa) has been evaluated as a growth inhibitor in the vigorous red apple cultivars 'Fuji' and 'Royal Gala'. Greatest inhibition of shoot growth was obtained when ProCa was first sprayed at about 200 mg L-1 from full bloom (FB) up to 12 days after full bloom (DAFB). Inhibition of shoot growth was due mainly to a reduction in internode length.

- The Prohexadione calcium (PCa), which is particularly effective and has the potential to increase the productivity of apple trees and reduce the need for pruning. Plants treated with PCa+TDZ in petal fall showed the highest values of fruit set and average number of fruits with floral clusters (Leite *et al.,* 2010).

3. Root initiation: A low concentration (10-10 to 10-9 M) of auxin promotes the growth of intact roots, whereas a higher concentration (10-6 M) inhibits root growth. Application of 1000 ppm p-hydro-xybenzoic acid + 5000 ppm IBA results in the maximum rooting percentage (85%), number of roots per cutting (56.9), length of longest root (23.2 cm) and survival percentage of cuttings (80.4%) in pomegr-anate cv. Kandhari (Tripathi and Shukla, 2004).

4. Flowering: In many woody plants including fruits GA inhibits flower formation. In these cases growth retardants viz., paclobutrazol, SADH which inhibits GA biosynthesis are used to promote flowering such as in pears and mango. Application of paclobutrazol helps in restricting the vegetative phase and increasing the reproductive phase of mango (Baghel *et al.,* 2004).

Soil application with 10 ml paclobutrazol resulted in the longest panicle (31.57 cm), number of branches per panicle (13), total number of flowers per panicle (620), number of hermaphrodite flowers (189.67) number of male flowers (425) and hermaphrodite flowers (30.59%). The male: hermaphrodite flower ratio was highest with application of 1% potassium nitrate in 10-year-old mango cv. Alphanso trees (Vijayalakshmi and Srinivasan, 2002).

5. Crop regulation: Plant bio-regulators have been found very effective in thinning flowers and manipulating the cropping season e.g., two sprays of 600- 800 ppm NAA done in April–May at 15 days interval in Tarai condition at 50% flowering is effective in regulating the crop in guava. On 20 years old Sardar guava trees NAA (600 ppm) application produced maximum winter crop yield (359.3 q/ha) followed by the application of 15 per cent urea (356.2 q/ha). The higher concentrations of urea were found very effective in improving the fruit quality and resulted in maximum TSS (14.0%), ascorbic acid (342.2 mg/100 g), total sugars (10.20%) and pectin (1.59%) content in the winter crop. Acidity was significantly reduced by 1800 ppm ethephon during both the seasons (Suleman *et al.,* 2006).

6. Fruit set and development: It is well known that PBRs are used on many fruit tree to manipulate immature fruit drop, fruit set or size and loosen or remove fruits.. A part from auxins and gibberellins, the growth retardents, ethylene inhibitors, polyamines and mixture of bioregulators have been found to increase fruit set. Pre-pollination applications of putrescine (1.0 and 0.01 mM) positively affect fruit set in Housui' after hand pollination (Mora *et al.,* 2004).

A mixture of GA4+7 and BA (Promalin) increase fruit shape, size and quality in Starking Delicious apple.

Effect of NAA on fruit crop

- Kacha *et al.,* (2012) studied that application of NAA in phalsa and recorded that spray of 200 ppm NAA resulted maximum height of bush (177.33 cm) and length of shoot (99.17 cm).
- Hasami and Abdi (2010) found that of NAA @ 100 ppm increased bunch weight, improved physical properties (fruit weight, height, diameter and size),

decreased TSS, total and reducing sugar in date palm.

- Kassem *et al.*, (2010) found that application of NAA at pea stage and marble stage in "Costata" persimmon significantly increased vegetative growth, fruit retention and fruit yield in both the seasons.
- Ghosh *et al.*, (2012) observed that spray of NAA at 15 ppm was the most effective in reducing the fruit drop at different months after fruit set which resulted in doubling of fruit production as compared to control and improved fruit size in sweet orange
- Pear fruit treated with NAA (20 ppm) have strong effect on fruit set and development (Chen *et al.*, 2012). The increase in fruit size as a result of foliar application of NAA might be because it had improved the internal physiology of developing fruit in terms of better supply of water, nutients and other compounds vital for their proper development which resulted in improving size (Jain and Dashora, 2010).

Effect of GA_3 on fruit crop

- Kumar *et al.*, (2012) observed that the application of GA_3 in strawberry at 80 ppm improved vegetative growth, runner production, ascorbic acid and acidity.
- Reddy and Prasad (2012) reported that the spray with GA_3 75ppm has increased fruit size and yield in pomegranate cv. Ganesh.
- Fruit sprayed with GA_3 (100 ppm) have retained maximum number of fruits in Amrapali due to the beneficial effect of GA_3 in delaying the formation of abscission layer. GA spray might have triggered auxin level and nullified the action of ABA consequently retained more fruit (Rani and Brahmachari, 2004).
- Sharma and Singh (2008) observed that application of GA_3 at 10 ppm in plum, proved more effective in promoting tree growth and fruit weight and volume and increased yield. Garner *et al.*, (2011) working in 'Hass' avocado reported that foliar application of GA_3 at 25ppm increased yield and fruit size.

Effect of 2,4-D on fruit crop

Nawaz *et al.*, (2008) found that foliar sprays of 2,4-D at 10ppm in Kinnow mandarin resulted in lowest fruit drop, increased number of fruits/plant and fruit weight/plant.

Amiri *et al.*, (2012) found that 60 ppm foliar spray of 2,4-D reduced pre harvest drop compare to control, significantly decreased percent of small, very small fruit size and increase large and marketable fruit size in Satsuma mandarin.

Reddy and Prasad (2012) reported that application of 2,4-D at 20, 30 and 40 ppm three times starting at full bloom and subsequently, at 45 and 90 days after fruit set in pomegranate cv. Ganesh, has resulted significantly increased fruit size in length, breadth and volume and higher fruit weight (262.23g), higher aril percent and maximum number of fruits (64.00) which resulted in highest fruit yield of 16.78 kg/plant.

Effect of Triacontanol on fruit crop

Shinde *et al.*, (2008) reported that in mango cv. Parbhani Bhusan spray of 700 ppm triacontanol at flowering, pea and marble stage of fruit development given maximum length (10.91 cm), breath (8.91 cm), volume (336.58 cm^3), weight (330.41 g), mesocarp (69.92%) and lowest proportion of endocarp (12.00%). Chowdhary *et al.*, (2009) found that spray with triacontanol 0.05 per cent in two cultivars of water chestnut and observed increased the volume of individual fruit by 45.32 per cent in Haldipada green and 47.11 per cent in Haldipada red cultivars and the fresh fruit yield also increased 32 per cent in green and 31.25 per cent in red cultivars.

Effect of growth regulator in fruit set and quality of fruit crops

Fruit (Variety)	PGR	Dose	Time of spray	Impact	Reference
Pear cv. Williams	GA_{4+7} +6BAi	6 mg/L	At full bloom	Increased fruit set	Luz *et al.*, (2014)
Pomegra-nate cv Bhagwa	NAA	40 ppm	Full bloom stage	Max. fruit weight, size and volume, increased TSS and total sugars	Anawal, Nara yanaswam, and Ekabote (2016)
Almond cv. Non pareil	Kinetin	50 micro litre/L	During bloom at pink bud	Increased fruit set	Maita and sotomayer (2015)
Guava	GA_3	200 ppm	stage Flower anthesis stage	Max. fruit length, diameter, weight and TSS	Mahmood, Hasan, Yonnus Ali, Ripa and Hossian (2016)
Sapota cv. Kallipatti	NAA	125 ppm	During flowe-ering and at pea stage	Max. fruit set perc-entage, fruit retent-ion and yield	Kaur (2017)
Custard Apple	GA_3	75 ppm	1st at flowering stage and 2nd at fruit set stage	Increased percen-tage of fruit set	Mahorkar, Naglot, Navsare and Chavhan (2018)
Datepalm cv. Barhee	GA_3 BAP Boric acid	100 ppm 100 ppm 250 ppm	Twice 1st at depressed period of fruit growth and 2nd one month after	Increased fruit set, retention and bunch weight	Ashour, Mostafa, Saleh and Hafez (2018)
Guava cv. Sardar	paclobu-trazol	500 ppm	Initiation of flowering	Max. fruit length, diameter, weight, volume and yield	Jain and Dashora (2010)
Mango cv. Langra	NAA NAA	10 ppm 15 ppm	Initiaion of flowering	TSS/acid ratio high, High ascorbic content	Singh *et al.*, (2011)

Conclusion

Plant growth regulators (PGRs) have emerged as a critical tool in modern fruit crop management, providing precise control over a wide range of physiological processes throughout a plant's lifecycle. Growers may control everything from seed dormancy and root initiation to vegetative vigour and flowering by strategically applying natural and synthetic phytohor-mones such as auxins, gibberellins, and growth retardants like paclobutrazol. Most notably, tailored PGR treatments consiste-ntly reduce pre-harvest fruit drop while increasing physical qualities like fruit size and boosting internal quality measures like total soluble solids and ascorbic acid conte-nt. Finally, successful integration of these bioregulators provides a highly effective technique for increasing both yield and economic value of various fruit crops, as long as the exact compound, concentration and phenological stage of treatment are carefully tuned. Finally, successful integration of these bioregulators provides a highly effective technique for increasing both yield and economic value of various fruit crops, as long as the exact compound, concentration, and phenological stage of treatment are carefully tuned.

References

Bisht, T. S., Rawat, L., Chakraborty, B., &Yadav, V. (2018). A recent advances in use of growth regulators (PGRs) in fruit crops - A review. International Journal of Current Microbiology and Applied Sciences, 7(5), 1307–1336.

Jain, M. C., & Dashora, L. K. (2010). Effect of different plant bio-regulators in relation to fruit quality and yield of guava (*Psidiumguajava* L.) cv. Sardar. Progressive Horticulture, 42(1), 50–53.

Singh, V. R., Mandal, B. K., & Singh, C. (2011). Effect of growth regulators and their concentration on fruiting yield, size and quality of mango cv Langra. Enviro-nment and Ecology, 29(1A), 306-309.

Suman, M., Sangma, P., Meghawal, D., & Prakash, O. (2017). Effect of plant growth regulators on fruit crops. Journal of Pharmacognosy and Phytochemistry, 6, 331–337.

ISSN No. 2583-3146

Microgreens: A Nutrient-Dense Functional Food for Next Generation

Vinay Kumar*, Aditya Kumar Giri and Simran

Department of Vegetable Science, SAAST, Chhatrapati Shahu Ji Maharaj University, Kanpur, Uttar Pradesh

Corresponding Author: gangwarv586@gmail.com

Introduction

Microgreens are young, tender vegetable greens harvested at an early stage of plantgrowth, generally 7-14 days after germination, when the cotyledon leaves have fully emerged and the first true leaves may begin to appear. These tiny greens, usually 1-3 inches tall, are positioned between sprouts and baby greens in terms of growth stage. Over the last decade, microgreens have evolved from being a decorative garnish in gourmet dishes to a widely recognized superfood due to their exceptional nutritional quality, vibrant colours, distinct flavours and health-promoting properties.

Microgreens can be produced from a wide variety of plant species, including vegetables, herbs, cereals, legumes and even some wild edible plants. Commonly cultivated microgreens include broccoli, radish, kale, mustard, fenugreek, cabbage, coriander, basil and amaranth. Their popularity is rapidly increasing because they are easy to grow, require minimal space and fit perfectly into modern urban agriculture systems such as vertical farming and hydroponics.

Nutritional Importance of Microgreens

One of the most remarkable features of microgreens is their high nutrient density. Microgreens may contain 4 to 40 times higher concentrations of vitamins, minerals and bioactive compounds than their mature counterparts. These nutrients include vitamins C, E and K, minerals like iron, zinc, magnesium, calcium and potassium and bioactive phytochemicals such as flavonoids, carotenoids, anthocyanins and polyphenols. For example, broccoli microgreens are particularly rich in magnesium, manganese, copper and zinc, while red cabbage microgreens contain nearly double the ascorbic acid content of mature cabbage leaves. Similarly, parsley microgreens possess significantly higher levels of lutein and beta-carotene, which are essential for eye health and antioxidant protection.

Nutritional composition of microgreens

Sample	AA (mg/ 100 g)	β-carotene (mg/100 g)	TC (mg/ 100 g)	Mg (mg/ 100 g)	Ca (mg/ 100 g)
Arugula	38.1	7.6	12.1	41	67
Broccoli	89.3	7.3	13.47	51	88
Brussel sprouts	64.3	6.9	11.4	49	81
Cauliflower	89.3	8.4	13.8	66	94
Coriander	48.3	6.7	13.0	-	-
Fenugreek	36.18	3.1	14.8	17.9	57.7
Kale Chinese	66.4	6.5	10.6	45	66
Pak choy	28.9	5.1	8.2	31	58
Rutabaga	29.7	6.8	8.6	44	59
radish	88.5	7.6	15.61	30.1	55.8

AA: Ascorbic acid; TC: Total Carotenoids

Vitamins

Microgreens are excellent sources of several essential vitamins:

- **Vitamin C (Ascorbic acid):** Important for immunity, collagen synthesis and antioxidant activity.
- **Vitamin E (α-tocopherol):** Protects cells from oxidative damage.
- **Vitamin K (Phylloquinone):** Essential for blood clotting and bone metabolism.

Roselle microgreens contain very high vitamin C content, while radish and cilantro microgreens are rich in vitamin E.

Carotenoids and Antioxidants: Carotenoids such as beta-carotene, lutein and zeaxanthin are abundantly present in microgreens. These compounds help in reducing oxida-tive stress and improve eye health. Red cabbage and cilantro microgreens are especially rich in carotenoids.

Mineral Composition: Microgreens are rich source of various macro (P, KCa and Mg,) and micro (Fe and Zn) nutrients. These minerals play critical roles in bone development, enzyme activation, oxygen transport and metabolic processes.

Health Benefits of Microgreens

Due to their rich phytochemical composition, microgreens offer several health benefits and are considered functional foods.

Antioxidant Properties

Microgreens possess strong antioxidant capacity because of their high concentration of vitamin C, vitamin E, polyphenols and carotenoids. These antioxidants neutralize harmful free radicals and reduce oxidative damage in cells.

Anti-Diabetic Effects

Broccoli and fenugreek microgreens have shown promising effects in controlling blood glucose levels. Studies reported that broccoli microgreens improve glycaemic control, antioxidant status and gut microbiota composition, making them beneficial for people with type 2 diabetes.

Cardiovascular Health

Cruciferous microgreens such as red cabbage and kale help reduce cholesterol and triglyceride levels. Their high content of glucosinolates and antioxidants contributes to better heart health.

Anti-Cancer Potential

Brassicaceae microgreens like broccoli, mustard and radish are rich in glucosinolates, which upon hydrolysis produce isothiocyanates such as sulforaphane. These compounds have been linked with anti-cancer and detoxification effects.

Growth Conditions and Cultivation

Microgreens are highly suitable for modern agriculture because they can be grown in controlled environments with minimal resources.

Growing Duration

Microgreens generally require only 7 to 14 days from sowing to harvest. This short growth cycle makes them economically attractive for commercial cultivation.

Growing Media

They can be grown on different substrates such as:

- Soil
- Cocopeat
- Vermiculite
- Peat moss
- Hydroponic pads
- Jute fiber mats

The choice of substrate influences growth, yield and nutritional quality.

Light Conditions

Light quality and intensity significantly affect nutrient accumulation. Blue and red LED lights are commonly used in controlled environment agriculture to enhance chlorophyll, carotenoid and anthocyanin content.

Temperature

The ideal temperature for microgreen cultivation ranges between 20-25°C, depending on the species.

Role in Sustainable Agriculture

Microgreens are highly relevant to sustainable agriculture and urban food systems.

Low Resource Requirement

Compared with conventional crops, microgreens require:

- Much less land
- Very less water
- No heavy pesticide use
- Minimal fertilizer

Broccoli microgreens use nearly 200 times less water than mature broccoli crops.

Vertical Farming

Microgreens are ideal for vertical farming systems due to their compact size and rapid growth. Vertical farming enables year-round production in urban spaces, reducing transportation costs and carbon footprint.

Hydroponics and Soilless Culture

Modern techniques like hydroponics, aeroponics and aquaponics are increasingly being used for microgreen production. These systems improve water-use efficiency and nutrient management while allowing precise environmental control.

Applications in Food Industry

Microgreens have gained importance in culinary and food processing industries.

They are used in:

- Fresh salads
- Sandwiches
- Soups
- Smoothies
- Juices
- Functional beverages
- Nutritional supplements
- Garnishing gourmet dishes

Because of their intense flavour and attractive appearance, they are also popular

ISSN No. 2583-3146

in restaurants and hotels. In addition, microgreens are now being explored as ingredients in value-added functional foods due to their high concentration of nutrients and phytochemicals.

Economic Importance

The commercial market for microgreens is expanding rapidly. According to the review, the global microgreen market was valued at $1.7 billion in 2022 and is expected to reach $3.4 billion by 2030, with a compound annual growth rate of 8.6%.

This increasing demand is driven by:

- Rising health consciousness
- Preference for clean-label foods
- Growth of plant-based diets
- Urban farming trends

Countries like India are also witnessing increasing interest in microgreen cultivation, especially among startups and urban farmers.

Conclusion

Microgreens represent an excellent combination of nutrition, health benefits, economic potential and sustainability. Their high nutrient density, medicinal properties, short production cycle and suitability for vertical farming make them an important crop for future agriculture and food security. As consumer demand for healthy and sustainable foods continues to grow, microgreens are expected to play a major role in modern horticulture, nutrition and functional food industries.

ISSN No. 2583-3146

Bioconversion of Agricultural Waste into Edible Mushrooms: A Sustainable Approach for Yield and Income Generation

Valenta Kangjam* and Anubhav Galav

Faculty of Agriculture & Veterinary Sciences, Mewar University, Chittorgarh, Rajasthan

Corresponding Author: Kangjam.valenta59@gmail.com

Introduction

Crop production systems generate large volumes of agricultural residues such as cereal straw, husks, maize stalks, and sugarcane by-products. In many regions, especially in northern India, these materials are frequently burned in fields, contributing to severe air pollution and declining soil health (Gupta *et al*., 2021). As a result, identifying sustainable and productive uses for these residues has become increasingly important.

Mushroom cultivation offers an efficient solution by converting agricultural wastes into nutrient-rich food. Edible fungi such as *Pleurotus*, *Agaricus*, *Lentinula*, and *Calocybe* possess lignocellulolytic enzymes that enable the breakdown of plant residues into edible biomass (Atila, 2023). In addition, mushroom farming offers a short production cycle approximately 30–45 days and relatively high returns, making it suitable for small-scale farmers and rural entrepreneurs. The rising demand for healthy and functional foods has further increased the market potential of mushrooms (Sharma *et al*., 2022). Thus, mushroom cultivation represents an important component of sustainable agriculture, where waste materials are efficiently transformed into food and organic inputs, supporting both environmental and economic sustainability.

Types of Agricultural Waste Used in Mushroom Cultivation

Various agricultural by-products can be effectively utilized as substrates due to their high lignocellulosic content.

Commonly used materials include

- Paddy straw
- Wheat straw
- Maize stalks and corn cobs
- Sugarcane bagasse
- Cotton waste
- Sawdust and wood residues
- Coconut husk
- Rice husk
- Banana leaves

Among these, wheat and paddy straw are most widely preferred because of their availability and suitability for mushroom growth. Studies have shown that oyster mushrooms cultivated on these substrates can achieve biological efficiency levels of 70–120%, indicating effective conversion of substrate into biomass (Royse *et al*., 2017).

Mushroom Cultivation Process Using Agricultural Waste

1. Preparation of Substrate: Agricultural residues are cut into smaller pieces, soaked in water to maintain adequate moisture (60–70%), and then pasteurized or sterilized to minimize contamination.

2. Inoculation (Spawning): Prepared substrate is inoculated with mushroom spawn and filled into bags or containers under hygienic conditions.

3. Incubation Phase: The inoculated substrate is kept under controlled temperature and humidity to allow complete colonization by fungal mycelium.

4. Fruiting and Harvesting: After colonization, environmental factors such as light, humidity (80–90%), and ventilation are adjusted to induce fruiting. Mushrooms are harvested at the appropriate stage of maturity.

Yield Performance

- **First flush:** approximately 400–600 g per kg substrate
- **Total yield:** about 1.0–1.5 kg per kg substrate
- **Crop duration:** 30–45 days

These values demonstrate the efficiency and productivity of mushroom cultivation systems under proper management.

Fig: Mushroom production process

Advantages of Using Agricultural Waste in Mushroom Production

Environmental Significance: Utilizing crop residues for mushroom cultivation helps reduce open-field burning and associated pollution problems. It also promotes recycling of organic matter, thereby contributing to environmental conservation.

Nutritional Importance: Mushrooms are considered a healthy food source due to their high protein content, dietary fibre, vitamins (especially B-complex and D), and essential minerals, while being low in fat.

Economic Potential: Mushroom farming requires relatively low investment and utilizes inexpensive raw materials. Farmers can generate additional income due to strong market demand.

Indicative Market Prices

- **Oyster mushroom:** ₹ 120 – ₹ 250 per kg
- Button mushroom: ₹ 200 – ₹ 400 per kg

Moreover, value-added products such as dried mushrooms, powders, pickles, and bakery items can further increase profitability and shelf life.

Utilization of Spent Mushroom Substrate

After harvesting, the remaining substrate still contains significant nutrients and organic matter. This material, known as SMS, can be reused in multiple ways.

Applications include

- Organic manure
- Soil conditioner
- Composting material
- Livestock feed supplement
- Biocontrol agent against certain soil pathogens

Research indicates that SMS improves soil structure, enhances microbial activity, and supports better crop growth, making it an important input in sustainable farming systems (Kumar *et al.*, 2023).

Contribution to Circular Bioeconomy

Mushroom cultivation supports a closed-loop agricultural system in which waste is continuously reused:

Crop residues → Mushroom production → Food (mushroom) → SMS → Soil enrichment

This approach minimizes waste generation while maximizing resource efficiency, aligning with the principles of circular bioeconomy and sustainable development.

Future Prospects

Ongoing research is focused on improving the efficiency and sustainability of mushroom-based systems, including:

- Development of innovative substrates from agro-industrial waste
- Enhancement of yield and biological efficiency
- Exploration of SMS as biofertilizer and biocontrol agent
- Integration with climate-resilient agricultural practices

These advancements are expected to strengthen the role of mushroom cultivation in sustainable agriculture.

Conclusion

The use of agricultural residues in mushroom cultivation offers a practical and sustainable method for managing crop waste while producing nutritious food and valuable by-products. By converting lignocellulosic materials into edible biomass and organic fertilizers, mushrooms contribute significantly to environmental protection, soil health, and farmer income. This integrated approach supports the transition towards a circular and sustainable agricultural system.

ISSN No. 2583-3146

Climate-Smart and Sustainable Horticulture: Forging Resilience in a Rapidly Changing World

Navnidhi Shrivastava

Department of Horticulture, SHUATS, Prayagraj, Uttar Pradesh

Corresponding Author: navnidhishrivastava1@gmail.com

Introduction

Horticulture occupies a distinctive niche within the global agricultural system - characterised by its diversity, labour intensity, ecological integration, and critical contribution to human nutrition. Yet the sector now faces mounting pressures of extraordinary scale. Climate change manifests through more frequent and severe droughts, unseasonal freezing events, erratic and intense precipitation episodes, and shifting distributions of pests and diseases - all of which jeopardise yields and erode farmer livelihoods. Across South Asia, sub-Saharan Africa, and the Mediterranean region, where smallholder horticulture underpins rural economies, the cost of inaction is both socially and economically severe.

Despite occupying only approximately 10% of cultivated land globally, horticulture generates nearly half of total agricultural income and remains indispensable to human health, supplying essential vitamins, minerals, dietary fibre, and antioxidants. Paradoxically, conventional production systems remain heavily input-dependent - relying on synthetic fertilisers, chemical pesticides, and water-intensive irrigation - while post-harvest losses may approach 45% in lower-income countries. Climate-smart approaches offer pathways to address each of these systemic inefficiencies, guiding the sector toward greater productivity and ecological integrity.

Climate-smart horticulture transcends mere technical problem-solving. At its core, it represents a fundamental philosophical shift: from extractive production towards regenerative stewardship, and from short-cycle yield maximisation towards durable ecological and economic sustainability. The five dimensions explored in this article collectively define this transformative agenda.

Understanding Climate-Smart Horticulture

The concept of "climate-smart agriculture" was introduced by the Food and Agriculture Organization of the United Nations in 2010, anchored in three core objectives: sustainably increasing agricultural productivity and farmer incomes; strengthening resilience and adaptive capacity to climatic stresses; and reducing or eliminating greenhouse gas emissions from the sector. When applied to horticulture, these objectives become deeply interdependent. Sustainable horticulture extends this framework by incorporating a fourth dimension: the multigenerational viability of farming systems, requiring ongoing soil health maintenance, reduced reliance on chemical inputs, water conservation, ethical treatment of farm labour, and the safeguarding of genetic diversity in cultivated and wild plant populations.

Climate-smart horticulture demands that ecological integrity and human wellbeing take precedence over short-term financial returns - treating soils, water resources, biodiversity, farming cmmunities, and governing institutions as components of a single interconnected system.

The stakes of this reorientation cannot be overstated. A horticultural system that progressively depletes its own resource base - exhausting soil nutrients, drawing down aquifers beyond their recharge rates, or eliminating populations of beneficial insects - ultimately destroys the ecological foundations upon which its own future productivity depends. In contrast, a system that actively rebuilds ecological capital while delivering high-quality, nutritious food represents a compelling model for the wider agricultural transformation that is now globally imperative.

Adaptive Strategies for a Changing Climate

Crop Diversification and Varietal Selection

Monocultural production systems are fundamentally fragile: a single outbreak of a pest or pathogen, or one anomalous weather event, can annihilate an entire season's harvest. Diversified farming arrangements - combining multiple species with varied growth habits, rooting depths, and harvest windows - distribute risk while generating beneficial ecological interactions, including natural pest suppression, enhanced soil fertility cycling, and localised microclimate regulation. Contemporary plant breeding has produced horticultural varieties with measurably improved tolerance to thermal stress, moisture deficit, waterlogging, and soil salinity.

Indigenous and traditional varieties, which commercial seed systems have largely marginalised, embody centuries of adaptive evolution under local environmental conditions and represent an underutilised reservoir of genetic resilience. Efforts to document, conserve, and reintroduce these landraces into active farming systems are a prerequisite for serious climate adaptation. Formal seed banks, community-managed seed libraries, and on-farm conservation programmes must be elevated to the status of core agricultural infrastructure.

Agroforestry and Shade-Based Systems

The deliberate incorporation of trees and woody perennials into horticultural landscapes delivers multiple climate-related benefits simultaneously. Tree canopies moderate thermal extremes at crop level, reduce wind-induced erosion, improve soil moisture retention through reduced evaporation, and provide refuge for pollinating insects and the natural enemies of crop pests. In tropical and subtropical contexts, shade-managed production systems have demonstrated that high-value horticultural crops can be cultivated in ways that preserve vegetation structure and support levels of biodiversity broadly comparable to natural ecosystems. In temperate regions, strategically placed windbreaks and shelter belts protect crops from physical damage, curtail evapotranspiration, and stabilise the microclimate — reducing frost risk and moderating diurnal temperature fluctuations.

The contribution of agroforestry to carbon sequestration is additionally significant: deep-rooted tree species accumulate carbon in above-ground biomass as well as in stabilised soil organic matter fractions, providing a meaningful mitigation function alongside their adaptation benefits.

Resource Stewardship: Water, Soil, And Energy

Precision Irrigation and Integrated Water Management

Agriculture is responsible for approximately 70% of global freshwater withdrawals, placing intensifying pressure on already stressed hydrological systems. Drip irrigation technology, which delivers calibrated water volumes directly to the root zone of individual plants, can reduce consumption by 30–60% relative to conventional flood or furrow irrigation, while concurrently suppressing weed establishment and lowering the incidence of fungal foliar diseases. Sensor-integrated precision irrigation systems advance this efficiency further by incorporating real-time data streams on soil volumetric water content, meteorological forecasts, and crop evapotranspiration requirements to automate scheduling with minimal reliance on manual judgment.

Rainwater harvesting infrastructure, treated greywater recycling, and managed aquifer recharge programmes complement field-level technologies, collectively constituting a comprehensive water stewardship framework suited to climate-variable conditions. In regions experiencing severe groundwater depletion — notably across much of the Indo-Gangetic Plain — such integrated water management approaches are not incremental improvements but essential prerequisites for long-term horticultural viability.

Soil Health and Regenerative Agronomic Practices

Soil biological health constitutes the fundamental basis of sustainable horticulture. Even a small sample of productive topsoil contains populations of microorganisms numbering in the billions, whose metabolic activities drive essential nutrient transformation cycles, suppress soil-borne pathogens, and construct the aggregate architecture that confers water-holding capacity and structural resilience. Conventional intensive horticulture, characterised by high synthetic input use and the repeated passage of heavy machinery, systematically degrades this biological capital, leaving soils compacted, biologically impoverished, and prone to erosion and surface runoff.

Regenerative horticultural practices reverse this pattern of degradation. Compost and vermicast applications rebuild soil organic matter pools and reintroduce biological diversity. Mulching suppresses moisture loss, buffers soil temperature variability, and supports the decomposer organisms that recycle nutrients. Intercropped cover crops - particularly nitrogen-fixing leguminous species - simultaneously suppress weeds, prevent erosion between main crop cycles, and contribute fresh organic matter on incorporation. Reduced and zero-tillage systems protect soil structural integrity and preserve the mycorrhizal fungal networks whose hyphal connections substantially extend the effective absorptive surface area of plant root systems. Collectively, these practices do not merely sustain current productivity - they build an increasingly fertile and self-renewing resource base over time.

Reducing the Energy Footprint of Protected Cultivation

Converting protected horticultural facilities to renewable energy sources - solar photovoltaic arrays, geothermal heat exchange systems, and biomass combustion - offers substantial reductions in operational carbon emissions. Passive energy design strategies including double-skin glazing, thermally controlled shade screens, and optimised structural orientation reduce heating and cooling energy demands at the design stage. In the Netherlands -

internationally recognised as a leader in controlled environment horticulture - many enterprises now operate at or near carbon neutrality in their energy balance, capturing and redistributing residual thermal energy from combined heat-and-power systems while recycling internally generated CO_2 as a crop growth promoter.

Biodiversity, Ecology and Integrated Pest Management

Biodiversity - at the level of the cultivated field and the broader agricultural landscape - is the fundamental basis of ecological resilience in horticultural systems. Genetically heterogeneous crops are inherently more resistant to catastrophic loss from any single pathogen or climatic perturbation. Ecologically complex farming landscapes that incorporate hedgerow networks, wildflower field margins, permanent water bodies, and woodland patches sustain populations of beneficial arthropods whose services - crop pollination and natural enemy activity against pests - underpin production without chemical inputs.

Integrated Pest Management (IPM) provides the operational framework through which this ecological capital is translated into effective crop protection. IPM assembles biological control measures - including the conservation and, where appropriate, augmentation of natural enemy populations such as parasitoid hymenoptera and predatory coleoptera - with cultural management practices such as crop rotation schedules, the deployment of host-plant resistance, and physical exclusion barriers. Chemical pesticide use is reserved as a last resort, applied only when economic thresholds are exceeded and only with selective compounds that minimise non-target impacts. Rigorously implemented IPM programmes consistently achieve pest regulation outcomes comparable to conventional chemical regimes while dramatically reducing pesticide residue loads in food and protecting non-target biodiversity.

The preservation of wild relatives of cultivated horticultural species in ex situ gene banks and in situ field reserves harbours genetic variation for disease resistance and abiotic stress tolerance that may prove indispensable as climatic conditions continue to deteriorate - representing a strategic biological reserve for the long-term viability of food production.

Investment in plant genetic resource conservation is simultaneously an expression of ecological responsibility and a forward-looking risk management strategy. Seed banks, participatory community seed networks, and on-farm agro-biodiversity maintenance must be recognised and funded as strategic agricultural infrastructure - not marginalised as peripheral conservation activities divorced from mainstream production.

Key Dimensions of Climate - Smart Horticulture

Dimension	Principal Actions and Expected Outcomes
Climate Adaptation	Diversified crop portfolios; heat- and drought-tolerant varieties; agroforestry integration; revised planting calendars; deployment of agro-meteorological early warning systems.
Water Stewardship	Drip and subsurface irrigation (30–60% water savings); sensor- automated scheduling; rainwater harvesting; managed aquifer recharge; treated effluent reuse.

Dimension	Principal Actions and Expected Outcomes
Soil Regeneration	Composting and vermicast application; leguminous cover cropping; organic mulching; conservation tillage; long-term accumulation of soil fertility and structural resilience.
Biodiversity & IPM	Ecological landscape design; natural enemy conservation and augmentation; diversified crop genetic portfolios; wild relative preservation; minimised pesticide dependence.
Technology & Data	Remote sensing and multispectral monitoring; drone-based crop surveillance; AI-assisted decision support systems; vertical farming; blockchain-enabled supply chain traceability.
Governance & Policy	Reoriented agricultural subsidy regimes; enhanced extension service delivery; expanded climate finance access; sustainability certification schemes; consumer-driven market incentives.

Table 1. Key dimensions of climate-smart horticulture and associated actions and outcomes.

Technology, Innovation and Digital Agriculture

Remote sensing platforms - including satellite-borne multispectral instruments, drone-mounted imaging systems, and ground-level sensor arrays - now enable growers to monitor crop physiological status, soil conditions, and incipient pest pressure across entire farm units with spatial and temporal resolution previously unattainable. Artificial intelligence and machine learning frameworks process these complex data streams to generate operationally actionable guidance - from precision-adjusting fertiliser application prescriptions to projecting disease outbreak risk several days in advance of observable symptoms.

Controlled environment agriculture (CEA), encompassing vertically stacked indoor production systems and technologically sophisticated greenhouse facilities, extends resource efficiency to its most advanced expression. Hydroponic and aeroponic growing configurations eliminate soil dependency entirely, reducing water consumption by up to 95% relative to open-field production and enabling viable cultivation in dense urban environments, arid regions, and climatically extreme locations. While the capital and energy requirements of CEA currently constrain widespread adoption, sustained innovation in LED photon delivery efficiency and circular nutrient management systems is progressively improving the economic and energetic viability of these approaches.

Distributed ledger technologies, including blockchain-based systems, are emerging as tools for enhancing transparency and accountability across horticultural supply chains - enabling retail buyers and end consumers to independently verify provenance, sustainability standards, and cold-chain handling conditions for fresh produce. Smartphone-based mobile platforms are bringing near-real-time weather information, commodity price data, and agronomic guidance directly to smallholder farmers in remote rural areas, addressing longstanding informational inequalities that have historically placed these producers at a structural disadvantage.

Policy, Markets and Governance

Technical innovation and individual farmer initiative, however impressive, are insufficient in isolation to catalyse the systemic transformation that climate-smart horticulture demands. Enabling governance frameworks, appropriately structured market incentives and sustained public investment are indispensable complements. Governments play a defining role through reorienting agricultural subsidy structures away from input-intensive conventional farming towards agroecologically grounded approaches; through strengthening agricultural extension systems that translate research outputs into farm level practice; and through establishing product certification frameworks that generate market premiums rewarding climate-smart production.

International climate finance instruments - including the Green Climate Fund and the Adaptation Fund - represent significant capital resources for equipping horticultural sectors in developing and climate-vulnerable countries with the knowledge infrastructure and investment capacity they require. However, the effective deployment of these resources is currently hampered by application procedures and fiduciary requirements designed for large instituti-onal actors, which effectively exclude smallholder farming organisations from access. Deliberate simplification of these pathways is an urgent governance priority.

Consumer behaviour and market price signals exercise substantial independent influence. Expanding demand for organically certified, locally sourced, and demonstrably sustainably produced food generates commercial rewards for producers who adopt more responsible practices. Retailers and food service corporations that embed environmental and social sustainability criteria into supplier procurement standa-rds are capable of driving change at scale through the governance power of their supply chains.

Challenges and Practical Pathways

Challenge	Practical Pathway
High capital and operational costs of precision technologies	Subsidised equipment leasing programmes; aggregation through farmer producer organisations; government-funded technology demonstration farms reducing perceived and actual adoption risk.
Inadequate climate literacy among smallholder producers	Krishi Vigyan Kendra demonstration sites; crop-stage-specific SMS advisory services; illustrated vernacular extension materials; local-language radio broadcasts.
Water scarcity in rain-dependent and groundwater-stressed regions	Community watershed governance frameworks; targeted drip drip irrigation subsidies; mandated rainwater harvesting in new agricultural infrastructure; low-water variety adoption incentives.
Soil degradation from prolonged intensive cultivation	Transition support and incentive programmes; organic matter improvement grants; compost production subsidies; mandatory soil health card issuance with remediation guidance.
Restricted market access for sustainably produced horticultural crops	Certification cost-sharing mechanisms; direct producer-to-consumer digital platforms; institutional procurement reform; green market premium development.

Challenge	Practical Pathway
Policy incoherence and perverse subsidy incentives	Independent policy impact reviews; subsidy reform implementation roadmaps; inter-ministerial coordination on agriculture and climate; strengthened civil society advocacy platforms.

Table 2. Barriers to climate-smart horticultural transition and evidence-informed practical responses.

Future Horizons

Nano-formulated micronutrient and soil amendment products enable deeper tissue penetration and controlled-release delivery over extended periods, achieving equivalent or superior agronomic outcomes at reduced dosage rates with diminished phytotoxicity risk compared to conventional formulations. Portable X-ray fluorescence leaf scanners and GPS-integrated smartphone diagnostic platforms are beginning to make site-specific, growth-stage-specific nutritional prescriptions operationally feasible, maximising input-use efficiency while reducing unnecessary expenditure. CRISPR-based precision gene editing, deployed with appropriate biosafety oversight and proportionate regulatory frameworks, holds promise for engineering targeted climate resilience traits in horticultural crops - complementing rather than displacing traditional and participatory breeding approaches.

High-resolution climate modelling and sub-seasonal forecasting tools, increasingly embedded within farm management software environments, are equipping growers to anticipate seasonal risks and adapt production strategies with months of lead time. AI-powered epidemiological surveillance networks, synthesising satellite-derived imagery with ground-sensor data streams, are progressively transforming the prevailing model of reactive crisis response into a proactive prevention paradigm. The coordinated convergence of these technologies - suppor-ted by commensurate investment in rural digital infrastructure and producer training capacity - holds genuinely transformative potential for the future of horticulture worldwide.

Conclusion

Climate-smart and sustainable horticulture is not a long-range aspiration - it is a present-day operational imperative. The converging trajectories of climate disruption, accelerating biodiversity erosion, and resource constraint leave no tolerable margin for delay, yet simultaneously provide both the motivation and the mandate for decisive transformative action. The strategies examined in this article - adaptive crop management, regenerative soil practices, precision resource stewardship, biodiversity-informed pest management, digital agricultural innovation, and enabling governance - are not independent interventions but mutually constitutive components of a coherent integrated system.

What fundamentally distinguishes genuinely climate-smart horticulture from incremental efficiency improvement is its systemic character: the recognition that soils, water cycles, atmospheric composition, biological diversity, farming families, consumers, and governing institutions are nodes within an interconnected system, and that effective solutions must engage this complexity rather than optimise any single variable in isolation. A producer who installs drip irrigation while continuing to deplete soil organic matter has resolved one problem while perpetuating another. A researcher who develops a drought-tolerant variety while neglecting questions of seed access, affordability, and farmer agency has generated knowledge without catalysing impact.

The path forward requires genuine cross-disciplinary, cross-sectoral, and cross-border collaboration. It demands serious intellectual engagement with the knowledge embedded in traditional and indigenous agricultural systems, even while harnessing the remarkable capabilities of contemporary science and technology. Above all, it necessitates sustained long-term commitment - from policymakers, agribusiness, research institutions, and farming communities alike - to situate ecological health and human welfare above short-term financial returns. In doing so, horticulture can realise its extraordinary dual potential: not only to nourish human bodies, but to rehabilitate degraded landscapes, contribute to climate stabilisation, and cultivate the conditions necessary for a genuinely sustainable civilisation.

❖❖

ISSN No. 2583-3146

Rooftop Gardening: A Solution for Landscape Enhancement in Urban Areas

Ansh Pratap Singh, Ajay Kumar Singh, Amit Kanawjia and Jai Ram*

Department of Floriculture and Landscape Architecture
Banda University of Agriculture and Technology, Banda, Uttar Pradesh

Corresponding Author: jairam16072001@gmail.com

Introduction

Cities across the world are expanding rapidly, resulting in increased built-up areas and reduced green cover. Conventional construction materials such as concrete and asphalt absorb and retain heat, significantly increasing ambient temperatures in urban areas. This phenomenon, known as the Urban Heat Island (UHI) effect, leads to higher energy consumption for cooling, deteriorated air quality, and thermal discomfort. Rooftop gardening refers to the cultivation of plants on the roofs of buildings. These systems range from simple container gardens to advanced engineered green roof systems incorporating multiple layers such as waterproof membranes, drainage systems, filter layers, growing media and vegetation. Rooftop gardens can be classified based on design intensity, purpose and structural complexity. Rapid urbanization and growing population pressures, cities around the world face unprecedented challenges including shrinking green spaces, rising temperatures, pollution and food security concerns. In this context, rooftop gardening and urban landscaping have emerged as innovative, sustainable solutions to mitigate urban environmental issues while enhancing aesthetic and social well-being.

Rooftop gardening refers to the cultivation of plants on the roofs of buildings, utilizing space that is otherwise unused and transforming it into productive green zones. Urban landscaping includes the planning and development of green spaces within cityscapes, integrating natural elements into built environments to improve ecological health and human quality of life.

History of Rooftop Gardens

The history of rooftop gardening dates back to ancient civilizations, where elevated green spaces were developed for aesthetic, cultural and practical purposes. One of the earliest examples can be traced to the ziggurats of Mesopotamia (around 4000–600 BC), which featured terraced structures that may have supported planted areas. The legendary Hanging Gardens of Babylon, considered one of the Seven Wonders of the Ancient World are often cited as a remarkable early example of rooftop or elevated gardening, built to recreate a lush mountainous landscape. In ancient Rome, villas such as the Villa of Mysteries in Pompeii incorporated roof terraces and courtyard gardens that functioned as social and recreational spaces. During the medieval period, Scandinavian countries developed sod roofs covered with grasses for insulation and structural stability. In the 20th century, Germany pioneered modern green roof technology, introducing engineered systems for waterproofing, drainage, and lightweight substrates. Today, rooftop gardening has evolved into a scientifically designed green infrastructure practice widely adopted in urban planning to enhance energy efficiency, environmental sustainability and urban resilience.

1. The Ziggurats of Ancient Mesopotamia
2. The Hanging Gardens of Babylon
3. The Villa of Mysteries, Pompeii
4. Norwegian Sod Roofs
5. Casino Theatre, New York City.

Need of Rooftop Gardening

Rooftop gardening is needed because rapid urbanization has reduced natural green spaces while increasing environmental problems such as the urban heat island effect, air pollution, high energy consumption, stormwater runoff, and loss of biodiversity. By converting unused roof spaces into vegetated areas, rooftop gardens help lower building temperatures, reduce the need for air conditioning, and improve overall energy efficiency. They absorb carbon dioxide and airborne pollutants, manage rainwater by reducing surface runoff, and create habitats for birds and

pollinators in densely populated cities. Additionally, rooftop gardens enhance urban aesthetics, improve mental well-being, support local food production and contribute to climate change mitigation. Therefore, rooftop gardening is an essential sustainable strategy for creating healthier, more resilient, and environmentally balanced urban environments

Type of roof top gardening

There are two main types of comprehensive and intensive green roof systems. Extensive green roofs are lightweight, have a narrow range of plants and are built for low maintenance; these green roofs differ in soil depths of 5-15 cm (2-6 in) with a weight increase of 70-170 kg/sq.ft (14-35 lb/ sq.ft), typically consisting of mosses and herbs and are distinguished by low capital costs, high plant variety and minimal maintenance needs. On the other hand, extensive green roofs have deep soils, a wide selection of plants and are built for human recreational use. These have a soil depth ranging from 20-60 cm (8-24 in) with a saturated weight increase of 290-967.7 kg/ sq. ft (60-200 lb/sq.ft). The roofs are frequently accessible and characterized by increased weight and structural implications, elaborate irrigation and drainage systems, increased plant diversity (trees and shrubs) and more maintenance needs. On the basis of uses and appearance, it is possible to categorize green roof and roof gardening into four forms.

Selection of plant species

Plant species selection is dependent on a number of factors: Different depth of the substrate supports different vegetation, for example, in extensive green roof, moss and sedum can be grown in 4-10 cm depth and moss, sedum and herbaceous plants can be grown in 5-11cm depth. In a depth of 15 - 25 cm and herbaceous plants can be grown. In roof garden, lawn shrub and trees can be grown. Trees can be grown in more than 50 cm depth of the growing medium.

Shrubs	Annuals	Climbers	Ground cover plants
Ficus benjamina	*Tagetes spp.*	*Jasminum officinale*	*Alternanthera sessilis*
Plumeria alba	*Dianthus barbatus*	*Pyrostegia vinusta*	*Alternanthera rinukii*
Bauhinia tomentosa	*Calendula officinalis*	*Hiptage benghalensis*	*Cholophytum comosum*
Ixora coccinea	*Chrysanthemum grandiflora*	*Jasminum auriculatum*	*Tradescentia pallida*
Hibiscus rosa sinensis	*Helichrysum bracteatum*	*Jasminum grandiflorum*	*Sphgneticala trilobata*
Duranta	*Dimorphotheca sinuta*	*Bauhinia vahlii*	*Catharanthus roseus*

Benefits and Constraints of Rooftop Gardening

Rooftop gardening offers multiple environmental, economic and social advantages in urban areas. One of its primary benefits is energy efficiency as green roofs act as natural insulation layers that reduce indoor temperatures during summer and minimize heat loss in winter, thereby lowering electricity consumption. They significantly mitigate the Urban Heat Island (UHI) effect by reducing roof surface temperatures. Rooftop gardens also improve air quality by absorbing carbon dioxide, nitrogen oxides and particulate matter, contributing to reduced pollution levels. In addition, they enhance storm water management by absorbing and retaining rainfall, which reduces runoff and urban flooding risks. Rooftop gardens support biodiversity by providing habitats for birds, pollinators and beneficial insects. They contribute to urban agriculture and food security by enabling the cultivation of vegetables, herbs and fruits in limited spaces. While also helping in noise reduction and partial carbon sequestration.

Strategies to Improve Rooftop Gardening

Improving rooftop gardening requires careful structural planning, scientific design and appropriate plant selection. Before installation, buildings should undergo structural assessment to ensure adequate load-bearing capacity, followed by the installation of high-quality waterproofing and drainage systems to prevent leakage and damage. The use of lightweight, engineered growing media can reduce structural stress while ensuring proper aeration and nutrient availability. Selecting climate-resilient, drought-tolerant and shallow-rooted plant species suited to rooftop microclimates improves survival and reduces maintenance requirements. Efficient irrigation systems such as drip irrigation, rainwater harvesting, and automated moisture sensors can optimize water use and enhance plant health.

Policy support and community engagement also play a crucial role in strengthening rooftop gardening initiatives. Government incentives, subsidies and green building regulations can encourage adoption at residential and commercial levels. Integrating rooftop gardens with solar panels (biosolar systems) can maximize space efficiency and energy production.

Future Trends

1. Integration of smart technology like sensors and IoT for monitoring soil moisture, temperature, and plant health.
2. Advances in hydroponics and vertical farming on rooftops to maximize space and yields.
3. Increasing government incentives and policies promoting urban agriculture.
4. Development of multifunctional green roofs combining solar panels and gardens.
5. Multidisciplinary approaches blending architecture, horticulture and ecology for innovative urban design.

Conclusion

Rooftop gardening and urban landscaping offer a powerful combination of ecological, social and economic benefits vital for sustainable urban development. By transforming unused spaces into green oases, cities can mitigate environmental challenges, enhance food security and improve citizens' quality of life. Continued research, supportive policies, community engagement and technological innovation are key to realizing their full potential in the urban future. It enhances building energy efficiency, mitigates environmental challenges, improves urban aesthetics, promotes biodiversity and strengthens food security.

Reference

Berndtsson, J. C. (2010). Green roof performance towards management of runoff water quantity and quality: *A review. Ecological Engineering,* 36(4), 351–360.

Getter, K. L., and Rowe, D. B. (2006). The role of green roofs in sustainable development. *HortScience*, 41(5), 1276–1285.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K. K. Y. and Rowe, D. B. (2007). Green roofs as urban ecosystems: Ecological structures, functions and services. *BioScience,* 57(10), 823–833.

Santamouris, M. (2014). Cooling the cities: A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy,* 103, 682–703.

Speak, A. F., Rothwell, J. J., Lindley, S. J. and Smith, C. L. (2012). Urban particulate pollution reduction by green roofs. *Environmental Pollution,* 159 (8–9), 2100–2107.

United Nations, Department of Economic and Social Affairs. (2019). *World urbanization prospects* 2018: Highlights. United Nations.

World Health Organization. (2017). Urban green spaces: A brief for action. WHO Regional Office for Europe.

Earth Pledge (2005). *Green Roofs: Ecological Design and Construction. Schiffer Publishing.*

Photographs of Some Indian Roof top gardening

❖❖

ISSN No. 2583-3146

Micro-Greens: A Concentrated Source of Nutritional Bioactives – A Review

Samir Ebson Topno*, Ikram Alam and Sonal Shikha

Department of Horticulture, NAI, SHUATS, Prayagraj, Uttar Pradesh

Corresponding Author: samirtopno@hotmail.com

Introduction

The global rise in non-communicable diseases (NCDs) such as diabetes, cardiovascular disorders, obesity, and hypertension has intensified the need for nutrient-rich foods that support preventive health. Rapid urbanization, sedentary lifestyles, and poor dietary habits have contributed significantly to this burden. Microgreens are young edible seedlings harvested shortly after the emergence of the first true leavesand have gained attention as a sustainable, nutrient-dense food source capable of enhancing dietary quality.

Microgreens are rich in vitamins, minerals, antioxidants, and plant secondary metabolites, often in concentrations several times higher than their mature counterparts. Their short cultivation cycle (10–15 days), minimal land requirement, and suitability for indoor or household production make them ideal for urban and peri-urban agriculture. Because they are consumed raw, nutrient losses are minimal, further enhancing their value as functional foods.

Historical Development

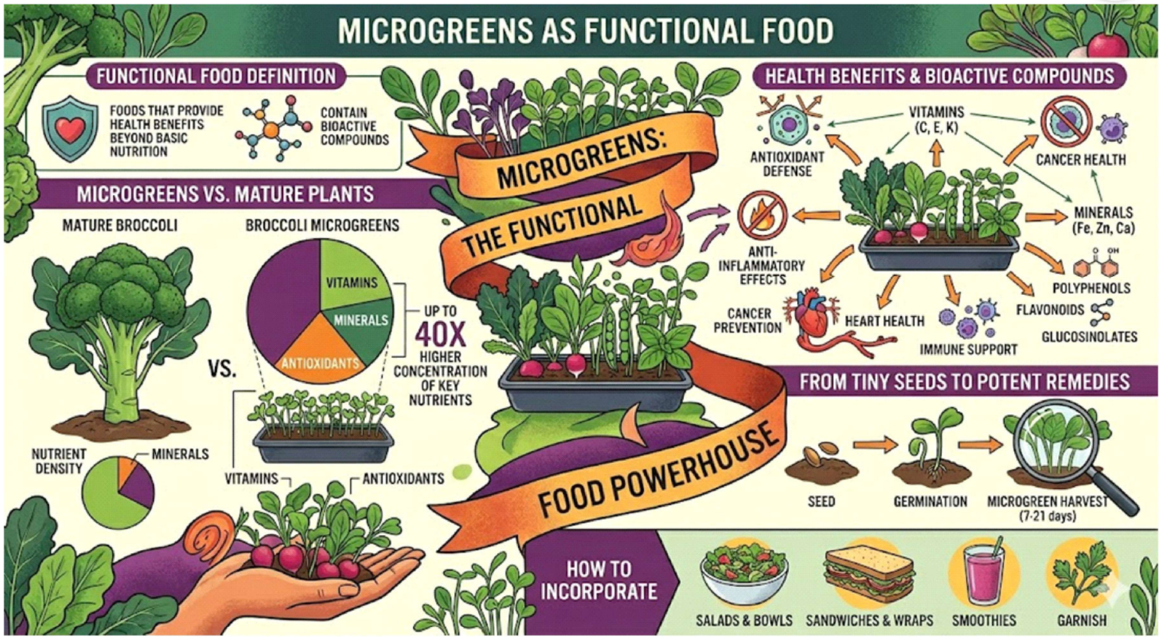
Although the modern term “micro-green” originated in the United States in the late 1990s, the consumption of young greens has deep historical roots. Wheatgrass, for example, has been used in Indian and Persian rituals for centuries and has long been valued in Ayurveda for its detoxifying properties. In the 20th century, wheatgrass gained popularity in the West through the work of Charles Schnabel and later Ann Wigmore, who promoted its health benefits.

By the early 2000s, chefs and specialty growers in North America began cultivating microgreens for gourmet cuisine. Their vibrant colors, delicate textures, and intense flavors quickly made them popular in fine dining. Today, microgreens are widely used in culinary applications and are increasingly incorporated into Indian cuisine by leading chefs, enhancing both visual appeal and nutritional value.

Nutritional and Functional Significance

Microgreens are recognized as functional foods due to their high concentrations of bioactive compounds. Studies have shown that they may contain four to six times more vitamins and carotenoids than mature vegetables. The USDA has reported significantly higher levels of vitamin C, vitamin E, β-carotene, and essential minerals in microgreens.

Different species exhibit distinct phytochemical profiles. Brassicaceae microgreens are rich in glucosinolates and polyphenols, which possess anti-cancer and anti-inflammatory properties. Amaranth microgreens



contain violaxanthin, lutein, and chlorogenic acid, while buckwheat microgreens demonstrate strong antioxidant activity due to their high phenolic content. Legume microgreens, such as pea and lentil, are notable for their flavonoid and polyamine content.

These bioactive compounds contribute to antioxidant defence, immune modulation, lipid regulation, and protection against chronic diseases. Animal studies have shown that red cabbage microgreens can reduce LDL cholesterol, inflammatory cytokines, and hepatic triglycerides, underscoring their therapeutic potential.

Diversity of Micro-Green Species

Globally, 70–80 plant species are cultivated as microgreens, spanning families such as Brassicaceae, Fabaceae, Amaranthaceae, Asteraceae, Lamiaceae, and Poaceae. Their colors range from green to purple, red, and variegated, making them visually appealing for culinary use. Popular species include radish, mustard, broccoli, amaranth, beet, basil, coriander, sunflower, pea shoots, and wheatgrass.

The choice of species influences not only flavor and appearance but also nutritional composition. For example, red cabbage and purple radish microgreens are rich in anthocyanins, while kale and broccoli microgreens contain high levels of vitamin K, calcium and iron.

Postharvest Challenges and Management

Microgreens are highly perishable due to their delicate tissues and high respiration rate. As the document states, "Micro-green is highly perishable, hence it cannot be stored or preserved over a long period," emphasizing the need for careful handling. Mechanical injury during harvesting accelerates senescence, making the use of sharp blades essential.

Temperature management is critical; storage at 1–5°C significantly slows metabolic activity and extends shelf-life. Packaging materials with high oxygen transmission rates (OTR) have been shown to maintain quality for up to 10–14 days. Edible coatings such as Aloe vera gel can further enhance shelf-life by reducing moisture loss and microbial growth. Pre-harvest calcium treatments have also been effective in improving tissue firmness and reducing electrolyte leakage.

Bio-Safety Considerations

Microgreens often exhibit higher initial microbial loads due to their proximity to the growing medium and the moisture retained after washing. Total aerobic mesophilic bacteria counts in unwashed microgreens can be higher than those in mature leafy vegetables. Proper sanitation, controlled washing, and the use of clean substrates are essential to ensure safety.

Wild species may accumulate nitrates or heavy metals, necessitating careful seed selection and monitoring of growing conditions. Pre-harvest calcium sprays and postharvest sanitization treatments can help reduce microbial contamination and improve shelf stability.

Conclusion

Microgreens represent a promising category of functional foods with exceptional nutritional density and health-promoting properties. Their ease of cultivation, rapid growth cycle, and suitability for small-scale and urban farming make them valuable for enhancing nutritional security. Despite challenges related to perishability and microbial safety, advances in postharvest handling and packaging technologies offer viable solutions. As consumer awareness grows, microgreens are poised to play an increasingly important role in sustainable diets and preventive health strategies.

References

Chandra, D., Kim, J. G., & Kim, Y. P. (2012). *Changes in microbial population and quality of microgreens during storage.* Horticulture, Environment, and Biotechnology, 53(6), 557–563. https://doi.org/10.1007/s13580-012-0102-0

De la Fuente, B., López-García, G., Maiani, G., & Ruales, J. (2019). *Evaluation of bioactive compounds and antioxidant capacity in Brassica microgreens.* Journal of Food Composition and Analysis, 82, 103–110. https://doi.org/10.1016/j.jfca.2019.103234

Ebert, A. W., Wu, T. H., & Yang, R. Y. (2014). *Nutritional composition and health benefits of amaranth microgreens.* Food Science and Human Wellness, 3(2), 56–60. https://doi.org/ 10.1016/j.fshw.2014.05.001

Huang, H., Jiang, X., Xiao, Z., & Wang, Q. (2016). *Red cabbage microgreens lower LDL cholesterol and hepatic lipid accumulation in mice fed a high fat diet.* Journal of Agricultural and Food Chemistry, 64(48), 9161–9171. https://doi.org/10.1021/acs.jafc.6b03707

Kou, L., Luo, Y., Yang, T., & Wu, D. (2013). *Postharvest physiology, quality, and shelf life of microgreens.* Postharvest Biology and Technology, 88, 1–7. https://doi.org/10.1016/j.postharvbio. 2013.09.006

Kou, L., Luo, Y., & Turner, E. R. (2015). *Quality and shelf life of packaged microgreens under different storage conditions.* LWT – Food Science and Technology, 62(1), 644–651. https://doi.org/10.1016/j.lwt.2014.06.047

Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., De Pascale, S., & Santamaria, P. (2016). *Micro scale vegetable production and the rise of microgreens.* Trends in Food Science & Technology, 57, 103–115. https://doi.org/10.1016/j.tifs.2016. 09.005

Kyriacou, M. C., *et al.*, (2019). *Nutritional and phytochemical diversity in microgreens.* Food Chemistry, 277, 107–118. https://doi.org/10.1016/j.foodchem.2018.10.098

Pinto, E., Almeida, A. A., Aguiar, A. A., & Ferreira, I. M. (2015). *Comparison of the mineral and phytochemical profiles of microgreens and mature plants of edible *species.* Journal of Food Composition and Analysis, 37, 38–43. https://doi.org/10.1016/j.jfca.2014.06.018

Xiao, Z., Lester, G. E., Luo, Y., & Wang, Q. (2012). *Assessment of vitamin and carotenoid concentrations in microgre-ens.* Journal of Agricultural and Food Chemistry, 60(31), 7644–7651. https://doi.org/10.1021/jf300459b

Xiao, Z., *et al.*, (2019). *Phytochemical profiles and nutrient composition of Brassica microgreens.* Food Chemistry, 290, 354–364. https://doi.org/10.1016/j.foodchem.2019.03.155.

❖❖

ISSN No. 2583-3146

Adoption Barriers of ICT among Farmers

Anjna Gupta* and Rashmi Shukla
KrishiVigyan Kendra, Jabalpur
Corresponding Author: blogger.sp2020@gmail.com

Introduction

MInformation and Communication Technology (ICT) has emerged as a powerful tool for transforming agriculture across the globe. From mobile-based advisory services to precision farming techniques, ICT has the potential to enhance productivity, improve decision-making, and connect farmers to markets. Despite these benefits, the adoption of ICT among farmers especially in developing countries remains uneven and limited. A significant gap exists between the availability of technological solutions and their actual use on the ground.

This article explores the major barriers that hinder the adoption of ICT among farmers. Understanding these challenges is essential for policymakers, researchers, and development organizations to design effective strategies that promote digital inclusion in agriculture.

Understanding ICT in Agriculture

ICT in agriculture includes a wide range of tools and technologies such as mobile phones, internet services, agricultural apps, satellite imaging, drones, sensors, and digital platforms. These technologies help farmers access real-time information about weather, soil health, crop management, pest control, and market prices.

While large-scale farmers and agribusinesses are increasingly using advanced ICT tools, smallholder and marginal farmers often face difficulties in adopting them. These difficulties arise from a combination of economic, social, infrastructural, and institutional factors.

Major Adoption Barriers

1. Lack of Digital Literacy

One of the most significant barriers to ICT adoption is the lack of digital literacy among farmers. Many farmers, particularly in rural areas, are not familiar with smartphones, mobile applications, or internet usage. Even when they own mobile devices, they may only use basic features like calling and texting.

Limited education levels further exacerbate this problem. Farmers may find it difficult to understand technical language, navigate digital platforms, or interpret data provided by ICT tools. As a result, they hesitate to adopt new technologies.

2. Poor Infrastructure

ICT tools rely heavily on infrastructure such as electricity, internet connectivity, and mobile networks. In many rural areas, these basic facilities are either unavailable or unreliable.

- Frequent power outages make it difficult to charge devices.
- Weak or inconsistent internet connectivity limits access to online services.
- Remote areas may lack proper network coverage.

Without a strong infrastructural foundation, even the most advanced ICT solutions cannot function effectively.

3. High Cost of Technology

The cost of acquiring and maintaining ICT tools is another major barrier. Smartphones, computers, sensors, and other digital devices can be expensive for small-scale farmers with limited income.

In addition to the initial investment, there are recurring costs such as:

- Internet data charges
- Maintenance and repair expenses
- Subscription fees for digital services

For many farmers, these costs outweigh the perceived benefits, leading to low adoption rates.

4. Lack of Awareness

Many farmers are simply unaware of the ICT tools and services available to them. Even when such technologies exist, information about them does not always reach rural communities.

Extension services and awareness campaigns often fail to cover all regions effectively. As a result, farmers continue to rely on traditional methods and miss out on the advantages offered by ICT.

5. Language and Cultural Barriers

Most ICT tools are designed in dominant or global languages, which may not be understood by local farmers. Language barriers make it difficult for farmers to interact with applications or interpret the information provided.

Cultural factors also play a role. Farmers may be skeptical about adopting new technologies that differ from traditional practices passed down through generations. Trust issues and resistance to change can slow down adoption.

6. Limited Technical Support

Even when farmers adopt ICT tools, they often lack access to technical support and training. If a device malfunctions or an application does not work properly, farmers may not know how to fix the issue.

The absence of local support centers or trained personnel discourages farmers from relying on ICT solutions. Without proper guidance, they may abandon the technology altogether.

7. Fragmented Land Holdings

In many developing countries, farmers operate on small and fragmented land holdings. Advanced ICT tools such as precision agriculture technologies are often designed for large-scale farming operations.

Small-scale farmers may find these tools irrelevant or unsuitable for their needs. This mismatch between technology design and farm size limits adoption.

8. Data Privacy and Security Concerns

With the increasing use of digital platforms, concerns about data privacy and security have also emerged. Farmers may worry about how their personal and agricultural data is being used.

Lack of transparency in data handling practices can lead to distrust. Farmers may hesitate to share information or use digital platforms if they fear misuse of their data.

9. Inadequate Government Policies

Government support plays a crucial role in promoting ICT adoption. However, in many cases, policies are either insufficient or poorly implemented.

Challenges include:

- Lack of subsidies for ICT tools
- Weak extension services
- Limited investment in rural infrastructure

Without strong policy support, the adoption of ICT remains slow and uneven.

10. Gender Inequality

Gender disparities also affect ICT adoption in agriculture. Women farmers often have less access to technology, education, and financial resources compared to men.

Social norms may restrict women's use of mobile phones or participation in training programs. As a result, they are less likely to benefit from ICT-based solutions.

Impact of These Barriers

The presence of these barriers has several consequences:

- **Low productivity:** Farmers miss out on advanced techniques that could improve yields.
- **Limited market access:** Lack of digital connectivity restricts access to better markets and fair prices.
- **Information gap:** Farmers rely on outdated or incomplete information.
- **Economic inequality:** Technological benefits are concentrated among larger or more educated farmers.

These challenges highlight the need for targeted interventions to ensure inclusive agricultural development.

Strategies to Overcome Adoption Barriers

1. Improving Digital Literacy

Training programs and workshops should be organized to educate farmers about ICT tools. Simple and practical demonstrations can help build confidence and skills.

2. Strengthening Infrastructure

Governments and private sectors must invest in rural infrastructure, including reliable electricity and internet connectivity. Expanding network coverage is essential for ICT adoption.

3. Making Technology Affordable

Subsidies, low-cost devices, and affordable data plans can encourage farmers to adopt ICT tools. Financial support mechanisms should be introduced for smallholder farmers.

4. Increasing Awareness

Awareness campaigns should be conducted through radio, television, and local community networks. Agricultural extension services must actively promote ICT solutions.

5. Localizing Content

ICT tools should be developed in local languages and tailored to regional needs. User-friendly interfaces can make technology more accessible to farmers.

6. Providing Technical Support

Establishing local support centers and helplines can help farmers resolve technical issues. Continuous support ensures sustained use of ICT tools.

7. Inclusive Policy Frameworks

Governments should design policies that support digital agriculture, including funding, training, and infrastructure development.

8. Promoting Gender Inclusion

Special initiatives should be launched to empower women farmers with access to ICT tools and training programs.

Conclusion

ICT has the potential to revolutionize agriculture by improving productivity, efficiency, and sustainability. However, the adoption of these technologies among farmers is hindered by multiple barriers, including lack of digital literacy, poor infrastructure, high costs, and social challenges.

Addressing these barriers requires a holistic approach involving governments, private organizations, and local communities. By improving accessibility, affordability, and awareness, it is possible to bridge the digital divide and ensure that all farmers benefit from technological advancements.

The future of agriculture depends on how effectively ICT can be integrated into farming practices. Overcoming adoption barriers is not just a technological challenge it is a critical step toward achieving inclusive and sustainable agricultural development.

References

Food and Agriculture Organization (FAO). (2017). *Information and Communica-tion Technology (ICT) in Agriculture: A Report to the G20 Agricultural Deputies.* Rome:

FAO.

World Bank. (2019). *ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions.* Washington, DC: World Bank.

International Telecommunication Union (ITU). (2020). *Digital Trends in Agriculture and Rural Development.* Geneva: ITU.

Organisation for Economic Co-operation and Development (OECD). (2021). *Digital Agriculture: Opportunities and Policy Challenges. Paris:* OECD Publishing.

Indian Council of Agricultural Research (ICAR). (2018). *Role of ICT in Agricultural Development in India.* New Delhi: ICAR.

Ministry of Agriculture and Farmers Welfare. (2020). *Digital Agriculture Initiatives in India*. Government of India.

Aker, J. C. (2011). *Dial "A" for Agriculture: A Review of Information and Communication Technologies for Agricultural Extension in Developing Countries.* Agricultural Economics Journal.

Mittal, S., Gandhi, S., &Tripathi, G. (2010). *Socio-Economic Impact of Mobile Phones on Indian Agriculture.* Working Paper, ICRIER.

International Food Policy Research Institute (IFPRI). (2018). *The Role of ICT in Agriculture and Food Security.*

Meera, S. N., Jhamtani, A., & Rao, D. U. M. (2004). *Information and Communication Technology in Agricultural* Development: A Comparative Analysis. Agricultural Research & Extension Network Paper.

❖❖

ISSN No. 2583-3146

Impact of Climate Change on Irrigation Water Demand

Rudraksh
Department of Irrigation and Drainage Engineering, SHUATS, Prayagraj, Uttar Pradesh
Corresponding Author: rudrakshk80@gmail.com

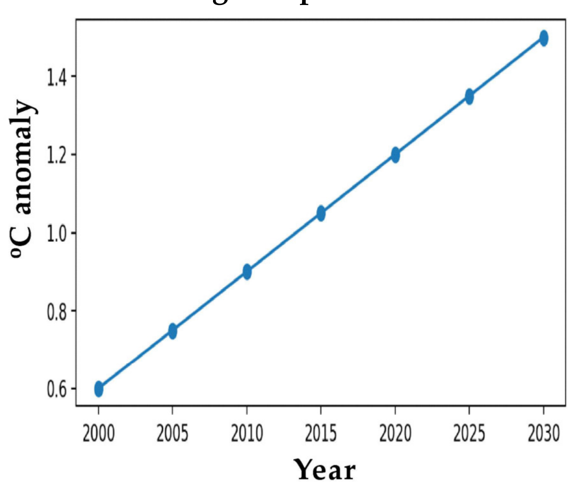
Introduction

Climate change refers to long-term changes in temperature, rainfall and weather patterns caused mainly by human activities. These changes directly affect agriculture and water resources. Irrigation is the artificial application of water to crops and is essential where rainfall is low or uncertain. Rising temperature increases evapotranspiration, while irregular rainfall reduces natural soil moisture. Therefore, irrigation water demand is increasing in many regions. Understanding this relationship is important for sustainable agriculture and food security.

Rising Temperature and Crop Water Requirement

Higher air temperature increases evaporation from soil and transpiration from plants. Together these processes are called evapotranspiration. When evapotranspiration rises, crops need more water to maintain growth. Heat stress can shorten crop duration and reduce yield if moisture is insufficient. Wheat often suffers during grain filling, rice requires careful water management during flowering, and maize is sensitive during tasseling. In hot climates farmers may need more frequent irrigation cycles. Increased nighttime temperatures can also raise respiration losses and lower productivity. Mulching, improved varieties and timely irrigation can reduce stress. Higher air temperature increases evaporation from soil and transpiration from plants. Together these processes are called evapotranspiration. When evapotranspiration rises, crops need more water to maintain growth. Heat stress can shorten crop duration and reduce yield if moisture is insufficient. Wheat often suffers during grain filling, rice requires careful water management during flowering, and maize is sensitive during tasseling. In hot climates farmers may need more frequent irrigation cycles. Increased nighttime temperatures can also raise respiration losses and lower productivity. Mulching, improved varieties and timely irrigation can reduce stress.

Rising Temperature Trend



Source: Unsplash / Public Domain Image

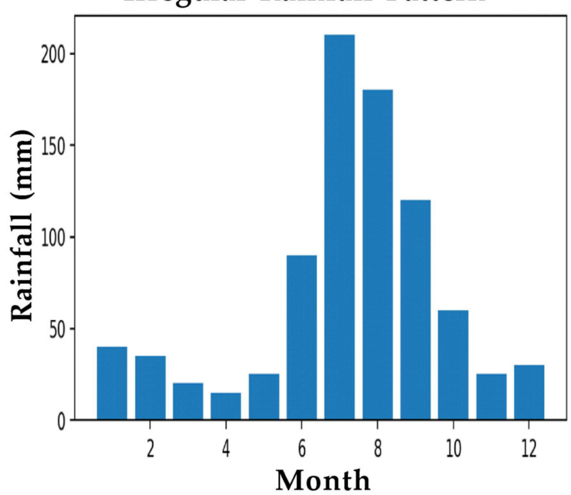
Changes in Rainfall Pattern and Water Availability

Climate change is causing rainfall to become more uncertain. Some areas receive intense short-duration storms, while others experience long dry spells. Heavy rainfall often leads to runoff rather than groundwater recharge, so available water may still remain low. Delayed monsoon onset can disturb sowing dates. Reduced winter rainfall affects rabi crops and stored reservoir water. Floods can damage canals, pumps and fields, while droughts lower river flows and tank storage. Better watershed management and rainwa-ter harvesting are increasingly important. Climate change is causing rainfall to become more uncertain. Some areas receive intense short-duration storms, while others experie-nce long dry spells. Heavy rainfall often leads to runoff rather than groundwater recharge, so available water may still remain low. Delayed monsoon onset can disturb sowing dates. Reduced winter rainfall affects rabi crops and stored reservoir water. Floods can damage canals, pumps and fields, while droughts lower river flows and tank storage. Better watershed management and rainwa-ter harvesting are increasingly important.

Effect on Irrigation Scheduling and Efficiency

Traditional fixed-date irrigation schedules are less reliable under changing weather conditions. Farmers need irrigation based on soil moisture, crop stage and weather forecasts. Efficient systems such as sprinkler and drip irrigation deliver water more uniformly and reduce losses. Laser land leveling can improve application efficiency in surface irrigation. Sensors and mobile advisory tools can help decide when and how much to irrigate. Scheduling based on crop evapotranspiration saves water and energy while maintaining yield.Traditional fixed-date irrigation schedules are less reliable under changing weather conditions. Farmers need irrigation based on soil moisture, crop stage and weather forecasts. Efficient systems such as sprinkler and drip irrigation deliver water more uniformly and reduce losses. Laser land leveling can improve application efficiency in surface irrigation. Sensors and mobile advisory tools can help decide when and how much to irrigate. Scheduling based on crop evapotranspiration saves water and energy while maintaining yield.

Irregular Rainfall Pattern



Source: Unsplash / Public Domain Image

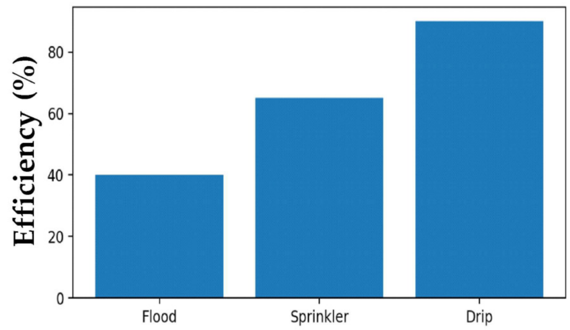
Groundwater Stress and Surface Water Resources

As rainfall becomes uncertain, dependence on groundwater often increases. Excessive pumping lowers the water table, raises pumping cost and may reduce water quality. In some regions salinity and fluoride problems become serious. Surface water resources such as rivers, lakes and reservoirs are also affected by reduced inflows and higher evaporation losses. Competition among domestic, industrial and agricultural sectors becomes stronger. Conjunctive use of surface and groundw-ater can improve reliability.As rainfall becomes uncertain, dependence on groundwater often increases. Excessive pumping lowers the water table, raises pumping cost and may reduce water quality. In some regions salinity and fluoride problems become serious. Surface water resources such as rivers, lakes and reservoirs are also affected by reduced inflows and higher evaporation losses. Competition among domestic, industrial and agricultural sectors becomes stronger. Conjunctive use of surface and groundwater can improve reliability.

Adaptation Strategies and Future Solutions

Adaptation is necessary to maintain production under climate stress. Farmers can adopt drought-tolerant and short-duration crop varieties. Shifting sowing dates can help crops avoid heat during sensitive stages. Micro-irrigation, deficit irrigation and fertigation improve water productivity. Farm ponds, check dams and recharge structures store excess rainwater. Digital tools using remote sensing and artificial intelligence can estimate crop water need in real time. Policy support, extension services and credit access are essential for large-scale adoption. Adaptation is necessary to maintain production under climate stress. Farmers can adopt drought-tolerant and short-duration crop varieties. Shifting sowing dates can help crops avoid heat during sensitive stages. Micro-irrigation, deficit irrigation and fertigation improve water productivity. Farm ponds, check dams and recharge structures store excess rainwater. Digital tools using remote sensing and artificial intelligence can estimate crop water need in real time. Policy support, extension services and credit access are essential for large-scale adoption.

Irrigation Efficiency



Source: Unsplash / Public Domain Image

Conclusion

Climate change is increasing irrigation water demand through higher temperature, uncertain rainfall and pressure on water resources. If irrigation practices remain inefficient, water scarcity will intensify. However, improved scheduling, efficient irrigation systems, groundwater management and climate-resilient crops can reduce risk. Integrated planning is required to ensure food security and sustainable use of water in the future. Climate change is increasing irrigation water demand through higher temperature, uncertain rainfall and pressure on water resources. If irrigation practices remain inefficient, water scarcity will intensify. However, improved scheduling, efficient irrigation systems, groundwater management and climate-resilient crops can reduce risk. Integrated planning is required to ensure food security and sustainable use of water in the future.

References

IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability.

FAO (2021). The State of the World's Land and Water Resources for Food and Agriculture.

IWMI (2020). Water Management under Climate Variability and Change.

ISSN No. 2583-3146

Preparation and Sensory Evaluation of Mixed Fruit Jam made from Natural Ingredients

Mashetty Rakesh Kumar*, Gunale A.V., Bharade S.S. and Phopase G.V.
Department of Horticulture, NSB College of Agriculture, Markhel, Dist. Nanded, Affiliated to Vasantrao Naik Marathwada Agriculture University, Parbhani, Maharashtra

Corresponding Author: rakeshkumarmashetty@gmail.com

Introduction

Mixed fruit jam is a popular confectionery product created by boiling fruit pulp with sugar, pectin, and acid to achieve a thick, spreadable consistency. Utilizing a combination of tropical and temperate fruits—such as papaya, pomegranate, apple, banana, grapes, and pineapple—allows for the development of a product with a unique, rich flavour profile and enhanced nutritional value compared to single-fruit jams. This study focuses on the experimental preparation and sensory evaluation of a multi-fruit blend, aiming to balance natural flavour, colour, and texture.Research into mixed fruit jam demonstrates that combining diverse tropical and temperate fruits—such as papaya, pomegranate, apple, banana, grapes, and pineapple—creates a nutritionally enriched product with superior organoleptic profiles.

Traditional jams often focus on single fruit types, but mixed formulations leverage the to develop a natural mixed fruit jam using a blend of papaya, pomegranate, apple, banana, grapes, and pineapple, evaluating its quality through physicochemical analysis and consumer acceptability.

Methodology

This methodology outlines the experimental procedure for developing a mixed fruit jam using papaya, pomegranate, apple, banana, grapes, and pineapple, incorporating natural ingredients for sensory evaluation and quality analysis based on established food science techniques.

(A) Experimental Design and Formulation

The experiment will be conducted at NSB College of agriculture, Markhelwith different ratios of pulp to evaluate the best formulation.

Sample ingredients ratios: Papaya (30%), Pineapple (20%), Apple (15%), Banana (15%), Grapes (10%), Pomegranate (10%)

(B) Materials and Preparation Method

Selection and Cleaning: Ripe, sound fruits (papaya, pineapple, apple, banana, grapes, pomegranate) are washed thoroughly to remove dirt.

Preparation: Peel, core, and slice the fruits into small pieces. Pomegranate seeds should be separated, and grapes deseeded.

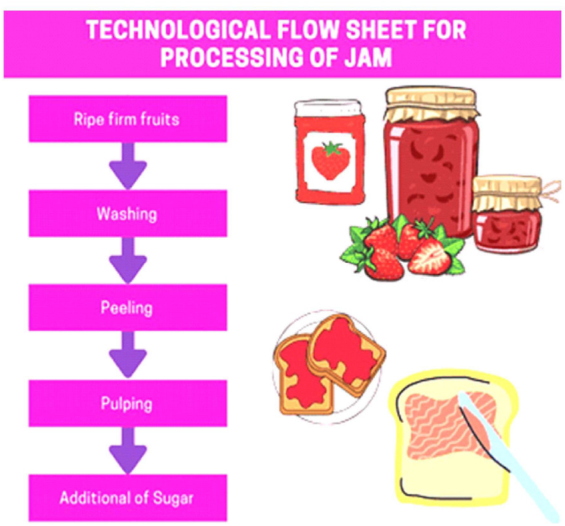
Pulping: Homogenize the fruits separately or together using a blender to create a uniform pulp.

Cooking:

- Add pulp to a heavy-bottomed pan and heat gently to soften the fruits.
- Add sugar (approx. 500g–750g per 1kg of pulp).
- Add natural pectin (if required, for setting) and citric acid/lemon juice to adjust pH to 3.0–3.3.
- Cook on medium-high heat while stirring continuously to prevent burning.

Endpoint Determination: Continue cooking until the total soluble solids (TSS) reaches 65–68°Brix (measured via hand refractometer) or until the "sheet test" is passed (jam falls from a spoon in sheets rather than drops).

Filling and Sterilization: Pour the hot jam (approx. 85°C) into pre-sterilized glass jars, leaving 1/4-inch headspace, and seal. The bottles are inverted to sterilize the lid.



(C) Sensory Evaluation Methodology

Sensory evaluation is conducted to assess the organoleptic qualities and consumer acceptability of the jam.

- **Panel Selection:** A panel of 10–30 semi-trained or trained judges is typically used.
- **Attribute Assessment**: Panelists rate the jam on specific attributes using a 9-point Hedonic Scale (where 9 = "Like Extremely" and 1 = "Dislike Extremely"). Key attributes include:
- **Appearance & Color:** Uniformity and brightness of the natural fruit pigments.
- **Aroma/Flavor:** Intensity and characteristic fruit notes.
- **Taste:** Balance of sweetness and tartness.
- **Texture & Spreadability:** Smoothness, gel strength, and ease of application on bread.

Sensory wheel developed with sensory attributes selected from the text-mining process.

Results and Discussion

Optimal Formulation & Preparation: Studies suggest that optimal jam formulations often require a balance where fibrous fruits (papaya/banana)are paired with acidic fruits (pineapple/pomegranate) to achieve a desired balance of consistency and pH. A blend (e.g., 150g pineapple: 150g papaya + other fruits) ensures good gelling and flavor.

Physicochemical Analysis

Total Soluble Solids (TSS): The TSS in well-prepared mixed jams typically ranges between 65–70° Brix, indicating proper sugar concentration for preservation.

Acidity & pH: Mixed jams often show a pH decrease and titratable acidity increase over time due to the interaction of acids from fruits like pomegranate and pineapple.

Moisture: Moisture content generally decreases over storage time (ranging from 17%–40% depending on formulation), contributing to a longer shelf life.

Sensory Evaluation (Organoleptic Assessment)

- **Color and Texture:** Papaya provides a good base texture, while pomegranate and grapes enhance the red color, leading to high consumer acceptability.
- **Flavor and Taste:** The combination of tropical fruits (pineapple/banana) and tart fruits (pomegranate/grapes) produces a complex, preferred flavor profile.
- **Overall Acceptability:** Mixed jams often score high in sensory tests (color, taste, texture, flavor) compared to commercial single-fruit jams.
- **Storage Studies:** Sensory characteristics, including color and aroma, tend to decrease slightly over a 10–12-week storage period; however, the jam remains safe for consumption.

Conclusion

Experimental studies on the preparation and sensory evaluation of mixed fruit jam using papaya, pomegranate, apple, banana, grapes, and pineapple generally conclude that a blended approach produces a nutritionally superior, highly acceptable product with better organoleptic properties than single-fruit jams. The combination of these specific fruits allows for a balanced blend of acidity (from pineapple, grapes, pomegranate) and body/texture (from papaya, banana, apple).

Overall, the experimental production of mixed fruit jam using a combination of these fruits provides a profitable and nutritious alternative to single-fruit products, with high potential for consumer acceptance.

References

Abolila, R. M., Barakat, H., El-Tanahy, H. A., & El-Mansy, H. A. (2015). Chemical, nutritional and organoleptical characteristics of orange-based formulated low-calorie jams. *Food and Nutrition Sciences*, 6, 1229–1244.

Afoakwa, E., Oguseye, O., Annor, G., & Ashong, J. (2006). Optimi zation of the processing conditions and quality characteristics of watermelon jams using response surface methodology. 13th *World Food Congress* (pp. 148–151).

Alizadeh, M. (2014). Effect of stevia as a substitute for sugar on physicochemical and sensory properties of fruit-based milk shake. *Journal of Scientific Research and Reports*, 3, 1421–1429.

Aishwaimi, E., Idrees, M., Berri, Z., El-Sakka, H., & Kujan, O. (2019). Association between diabetes mellitus and periodontal diseases: A survey of the opinions of dental professionals. *Medical Principles and Practice*, 28(2), 141–149.

AOAC. (2011). Official methods of analysis. Washington, DC: Association of Official Analytical Chemists.

AOAC. (2012). Official methods of analysis. Washington, DC: Association of Official Analytical Chemists.

Aprikian, O., Duclos, V., Besson, C., Manach, C., Morand, C., Rémésy, C., Demigné, C., Guyot, S., & Bernalier, A. (2003). Apple pectin and a polyphenol-rich apple concentrate are more effective together than separately on cercal fermentations and plasma lipids in rats.

The Journal of Nutrition, 133, 1860–1865.

Aslam, A., Zahoor, T., Khan, M. R., Khaliq, A., Nadeem, M., Sagheer, A., Chugtai, M. F. J., & Sajid, M. W. (2019). Studying the influence of packaging materials and storage on the physio chemical and microbial characteristics of black plum (Syzygium cumini) jam. *Journal of Food Processing and Preservation*, 43, e13941.

Atta, K., Ekissi, G. S. E., Ya, C. K., Fagbohoun, B. J., & Patrice, L. (2021). Physicochemical and sensory parameters of cashew apple jam (Anarcadium occidental L.) harvested in Bondoukou area (North East, Côte d'Ivoire). Open Access Research *Journal of Biology and Pharmacy,* 2,31–40.

Becker, S. L., Chiang, E., Plantinga, A., Carey, H. V., Suen, G., & Swoap, S. J. (2020). Effect of stevia on the gut microbiota and glucose tolerance in a murine model of diet-induced obesity. *FEMS Microbiology Ecology,* 96, 79.

Chandrasekaran, M., & Bahkali, A. H. (2013). Valorization of date palm (Phoenix dactylifera) fruit processing by-products and wastes using bioprocess technology–review. *Saudi Journal of Biological Sciences,* 20, 105–120.

Dupont, M. S., Bennett, R. N., Mellon, F. A., & Williamson, G. (2002). Polyphenols from alcoholic apple cider are absorbed, metabolized and excreted by humans. *The Journal of Nutrition,* 132, 172–175.

Elleuch, M., Besbes, S., Roiseux, O., Blecker, C., Deroanne, C., Drira, N.-E., & Attia, H. (2008). Date flesh: Chemical composi tion and characteristics of the dietary fibre. *Food Chemistry,* 111, 676–682.

Falade, K. O., & Abbo, E. S. (2007). Air-drying and rehydration characteristics of date palm (Phoenix dactylifera L.) *fruits. Journal of Food Engineering,* 79, 724–730.

Hussain, I., Zeb, A., Shakir, I., & Sattar Sha, A. (2007). Combine effect of potassium sorbate and sodium benzoate on individual and blended juices of apricot and apple fruits grown in Azad Jammu and Kashmir. *Pakistan Journal of Nutrition,* 7, 181–185.

Ishiwu, C., & Oluka, S. (2004). Development and performance eva luation of a juice extractor. Proceedings of the 5th International Conference and 26th Annual General Meeting of the Nigerian Institution of Agricultural Engineers (pp. 391–395).

Khan, A., Shah, F. N., Zeb, Q., Zeeshan, M., Iqbal, H., & Noor, H. (2020). Preparation and development of fig fruit jam blended with different level of apple pulp. *Biological Sciences*—PJSIR, 63, 105–112.

Khan, R. U., Afridi, S. R., Ilyas, M., Sohail, M., & Abid, H. (2012). Development of strawberry jam and its quality evaluation during storage. *Pakistan Journal of Biochemistry and Molecular Biology,* 45(1), 23–25.

Kim, M. J., Zheng, J., Liao, M. H., & Jang, I. C. (2019). Over expression of Sr UGT 76G1 in stevia alters major steviol glyco sides composition towards improved quality. *Plant Biotechnology Journal,* 17, 1037–1047.

Lal, G., Siddappa, G. S., & Tandon, G. L. (1960). Preservation of fruits and vegetables. *Indian Council of Agricultural Research.*

Lawless, H. T., & Heymann, H. (2010). Sensory evaluation of food: *Principles and practices. Springer.*

Leontowicz, M., Gorinstein, S., Bartnikowska, E., Leontowicz, H., Kulasek, G., & Trakhtenberg, S. (2001). Sugar beet pulp and apple pomace dietary fibers improve lipid metabolism in rats fed cholesterol. *Food Chemistry,* 72,73–78.

ISSN No. 2583-3146

Development of Biofortified Vegetable Varieties – A Solution for Global Health

M. Tulasi Achary*, Samir Ebson Topno, Lalita Lal

Department of Horticulture SHUATS, Naini Agriculture University, Prayagraj, Uttar Pradesh

Corresponding Author: tulasiachary7@gmail.com

Introduction

Micronutrient deficiencies affect more than two billion people globally, particularly in developing countries where diets are predominantly cereal-based. Vegetables represent a diverse group of crops that provide essential nutrients such as vitamin A, C, E, folate, iron, zinc, and beneficial phytochemicals. However, their nutrient content often varies across genotypes and may not meet the required dietary needs. Biofortified vegetables are nutrient-enhanced crops bred to tackle micronutrient deficiencies (e.g., vitamin A, iron) in populations relying on staple diets. By boosting traits like beta-carotene or zinc, they combat "hidden hunger" sustainably.

Biofortification is a cost-effective, food-based intervention aimed at enhancing the nutritional quality of staple crops and vegetables through various breeding and biotechnological methods.

Need for Biofortification in Vegetables

- High prevalence of vitamin A, iron, and zinc deficiency in developing countries.
- Limited access to diverse diets in rural populations.
- Nutrient loss during processing, cooking and storage.
- Growing consumer preference for nutrient-rich and functional foods.
- Opportunity to enhance indigenous and underutilized vegetables.
- Vegetables are ideal candidates for biofortification as they contain natural pigments (carotenoids, anthocyanins, flavonoids), antioxidants, and minerals.

Approaches for Developing Biofortified Vegetable Varieties

a. Conventional Breeding

- Selection of high-nutrient landraces and wild relatives.
- Hybridization to combine high nutrient content with yield and quality.
- Recurrent selection for traits like high carotenoid, lycopene, or iron content.
- Example: High β-carotene carrots and pumpkins developed through phenotypic selection.

b. Mutation Breeding

- Enhances specific nutrient traits without changing the crop's background.
- Gamma radiation, EMS commonly used.
- Example: Deep-orange mutant carrot lines rich in carotenoids.

c. Molecular Marker-Assisted Breeding (MAB)

- QTL mapping for nutrients such as β-carotene, folate, ascorbic acid.
- Faster and more precise selection.
- Used in tomato for lycopene and carotenoid biosynthesis genes.

d. Genetic Engineering

- Overexpression or silencing of key

pathway genes.

- Golden Rice-type strategies applied to vegetables.
- Example: Transgenic tomato for high lycopene and anthocyanin.

e. CRISPR–Cas Genome Editing

- Highly specific and efficient modification of nutrient biosynthesis genes.
- Used to enhance vitamin C and carotenoid pathways.
- Non-transgenic (gene-edited) varieties gaining regulatory acceptance.

f. Agronomic Biofortification (Complementary Approach)

- Application of micronutrient fertilizers (Zn, Fe, B)
- Enhances nutritional content during growth
- Often combined with genetic biofortification.

Key Target Nutrients in Vegetable Biofortification

Nutrient	Health Importance	Examples of Target Crops
β-carotene (Vitamin A)	Vision, immunity	Carrot, pumpkin, sweet potato, tomato
Lycopene	Anti-cancer	Tomato, watermelon
Iron	Anaemia prevention	Amaranthus, spinach, drumstick
Zinc	Immune function	Cabbage, leafy Brassicas
Folate	Pregnancy health	Spinach, broccoli
Anthocyanins	Antioxidants	Brinjal, purple cabbage

Examples of Biofortified Vegetable Varieties

A. Tomato

- PusaRohini (IARI) – high lycopene (8–10 mg/100g)
- Pusa Hybrid-8 – enhanced β-carotene
- Transgenic purple tomato – high anthocyanin (research stage)

B. Carrot

- High β-carotene orange carrots developed through selection

C. Purple/black carrots rich in anthocyianins (India & Europe)

D. Pumpkin

- Varieties rich in β-carotene and carotenoids, e.g., CO_2, ArkaSuryamukhi

E. Sweet Potato (Vegetable Category)

- Orange-fleshed sweet potato (OFSP): Internationally recognized for high vitamin A.

F. Leafy Vegetables

- Amaranthus varieties enriched with iron & calcium
- Breeding efforts in spinach for high folate content

G. Brassicas

- Broccoli biofortified with glucosinolates and antioxidants
- High-vitamin C cabbage lines under development

Challenges in Biofortification

- Negative correlation between yield and nutrient traits
- Limited natural genetic variability for some micronutrients.
- Consumer acceptance of unconventional colours (purple tomato).
- Need for stable expression across environments.
- Regulatory issues for GM and gene-edited vegetables.

Future Prospects

- Integration of omics tools: genomics, metabolomics, nutrigenomics.
- Speed breeding and genomic selection for rapid improvement.

- Use of wild relatives to broaden nutrient gene pools.
- Development of multi-nutrient biofortified varieties.
- Focus on underutilized vegetables such as moringa, taro leaves and pumpkin greens.

Conclusion

Biofortification of vegetables is a promising, sustainable, and long-term solution to reduce micronutrient malnutrition. Advances in plant breeding, biotechnology, and genome editing have accelerated the development of nutrient-rich vegetable varieties. Widespread cultivation and consumption of biofortified vegetables can significantly contribute to public health, especially in nutritionally vulnerable populations.

The development of biofortified vegetable varieties represents a sustainable solution to address micronutrient malnutrition, particularly in resource-limited communities. By enhancing nutrient content through breeding, these varieties improve public health, support food security, and empower farmers economically. Collaborative efforts in research, policy support, and awareness will ensure their adoption, making nutrition accessible and scalable. A healthier future starts with a nutrient-rich plate.

References

Bouis, H. E., & Saltzman, A. (2017). Improving nutrition through biofortification: A review of evidence from Harvest Plus, 2003 through 2016. Global Food Security, 12, 49–58.

Garg, M., Chawla, M., Chunduri, V., et al., (2018). Biofortification: A novel approach to eradicate micronutrient deficiency. Plant Biotechnology Journal, 16(11), 1996–2014.

Singh, D., & Kala, S. (2022).Biofortification in horticultural crops - Current status and future prospects Journal of Applied Horticulture, 24(1), 1–10.

Welch, R. M., & Graham, R. D. (2004). Breeding for micronutrients in staple crops. Journal of Experimental Botany, 55(396), 353–364. (Foundational paper on biofortification, frequently cited.)

Finkelstein, J. L., Haas, J. D., & Mehta, S. (2017). Iron-biofortified crops for improving iron status: A review of the current evidence. Nutrition Reviews, 75(9), 723-743.

Kumar, S., Singh, B., &Verma, P. (2020). Biofortification in vegetable crops: Technological approaches and challenges. Vegetable Science, 47(2), 125–132.

Rai, N., & Yadav, D. S. (2005). Advances in Vegetable Production. Chapter on nutritional improvement & breeding approaches.

Padulosi, S., Hunter, D., & Bharucha, Z. (2018). Seeds for nutritious diets: Learning from the biodiversity-rich regions of India. Bioversity International.

Chaurasia, S. N. S., & Singh, D. (2017). Breeding strategies for micronutrient-rich vegetables.In: Recent Advances in Vegetable Production and Breeding.

Indian Council of Agricultural Research (ICAR). Annual Reports & Variety Release Documents (2015–2024)– Contains information on iron-, zinc-, beta-carotene–rich vegetable varieties.

HarvestPlus (CGIAR). Biofortification Progress and Achievements Report (2014–2023).

FAO (Food and Agriculture Organization). Biofortification: A Food Systems Solution to Micronutrient Deficiency (2020).

WHO (World Health Organization). Guidelines on Micronutrient Deficiency and Fortified Crops.

Bouis, H., & Welch, R.Biofortification: Breeding Micronutrient-Dense Crops (Harvest Plus Handbook).

Peter, K. V. (Ed.). (2016). Horticulture Crop Breeding– Includes biofortified vegetable breeding methods.

Chattopadhyay, A. (2019). Vegetable Crops: Improvement and Production Technology– Contains micronutrient enhancement chapters.

ISSN No. 2583-3146

Vertical Gardening in Flower Crops: A Modern Approach to Space-Efficient Floriculture

Ashwani Kumar, Medha Saha* and Menkarani

Depatment of Floriculture and Landscaping, Pt. Kishori Lal Shukla College of Horticulture and Reseach Station Rajnanadgaon, MGUEVV, Durg, Chattisgarh

Corresponding Author: medhasahams@gmail.com

Introduction

Rapid urbanization and shrinking land availability have posed significant challenges to conventional floriculture practices. In response, vertical gardening has gained popularity as a viable solution for maximizing productivity within limited space. This method involves growing plants in vertically arranged structures, making it highly suitable for urban environments, balconies, terraces, and indoor spaces.

In the context of flower crops, vertical gardening not only enhances production efficiency but also improves aesthetic appeal, making it an integral component of modern landscape design.

Concept of Vertical Gardening

Vertical gardening refers to the cultivation of plants on upright surfaces using containers, panels, or hydroponic systems. Unlike traditional horizontal cultivation, it optimizes vertical space, allowing more plants to be grown per unit area. This system can be soil-based or soilless (hydroponics), depending on the design and resource availability.

Types of Vertical Gardening Systems

1. Wall-mounted Systems: Plants are grown in panels or pockets attached to walls.

- **Trellis and Climbing Structures:** Suitable for climbers and trailing flowering plants.
- **Stacked Pots or Tower Gardens:** Multiple pots are arranged vertically in tiers.

2. Hydroponic Vertical Systems: Nutrient solutions are used instead of soil for plant growth.

Suitable Flower Crops

The selection of appropriate flower crops is crucial for successful vertical gardening.

Ideal crops include:

Petunia (Petunia hybrida),
Pansy (Viola tricolor),
Marigold (Tagetes spp.),
Begonia (Begonia spp.),
Portulaca (Portulaca grandiflora),
Verbena (Verbena spp.),
Nasturtium (Tropaeolum majus),

These species are preferred due to their compact growth, adaptability, and ornamental value.

Cultural Practices

1. Growing Medium: A lightweight, well-drained medium such as cocopeat, perlite, and vermiculite is recommended.

2. Irrigation: Drip irrigation or mist systems are commonly used to ensure uniform water distribution.

3. Nutrient Management: Regular application of water-soluble fertilizers supports healthy growth and flowering.

4. Light Requirement: Adequate sunlight (4–6 hours daily) is essential for most flowering plants.

5. Maintenance: Periodic pruning, deadheading and pest management are necessary to maintain plant health and aesthetics.

Advantages

- Efficient use of limited space
- Enhanced aesthetic appeal
- Improved air quality in urban areas
- Ease of maintenance and harvesting
- Suitable for indoor and outdoor environments

Limitations

- Initial installation costs may be high.
- Requires proper irrigation and drainage systems.
- Limited suitability for large plants.
- Risk of water leakage and structural damage.

Applications in Floriculture

Vertical gardening is widely used in:

- Urban landscaping and smart city projects
- Balcony and terrace gardening
- Commercial flower production in limited spaces
- Interior decoration in homes, offices, and malls
- Exhibition and display purposes

Step-by-step visual snapshot of the process of making a vertical floriculture garden

1. Planning & Structure Setup

- Choose a wall (sunlight is important)
- Install a frame, rack, or panel system
- Materials: wood, metal grid, plastic panels

Setup Process

1. Build structure
2. Fix pots/pockets
3. Add soil + flowers
4. Set watering system
5. Maintain regularly

2. Installing Containers / Pockets

- Attach pots, grow bags, or pocket panels
- Ensure proper spacing for plant growth
- Make sure drainage holes are present

3. Soil Filling & Plant Selection

- Use lightweight, nutrient-rich soil mix
- Choose flowering plants like:
  - Petunia
  - Marigold
  - Begonia
  - Pansy
- Place taller plants at top, trailing plants below

4. Irrigation System Setup

- Install drip irrigation or water manually
- Ensure water flows from top to bottom evenly
- Avoid waterlogging

5. Final Maintenance & Bloom Stage

- Regular pruning
- Add fertilizers occasionally
- Replace weak plants
- Enjoy a beautiful flowering wall garden

Future Prospects

With advancements in hydroponics, automation and smart irrigation systems, vertical gardening holds immense potential in the floriculture sector. Integration with sustainable practices and climate-resilient technologies can further enhance productivity and environmental benefits.

Conclusion

Vertical gardening represents a transformative approach in the cultivation of flower crops, addressing the challenges of space constraints and environmental sustainability. Its adaptability, aesthetic value, and efficiency make it a promising technique for the future of urban floriculture and landscape design.

ISSN No. 2583-3146

Seed Priming and Seed Fortification: Unlocking the Full Potential of Seeds for Modern Agriculture

Neha A R*, Saklain Mulani and Suchitra B

Department of Fruit Science, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram, Kerala

Corresponding Author: nehaar2301@gmail.com

Introduction

Seeds are the foundation of agriculture. For millennia, farmers have relied on the seed's inherent ability to germinate, establish, and grow into a productive plant. However, in an era of climate uncertainty, soil degradation, and ever-growing food demand, relying solely on the seed's natural germination capacity is no longer adequate. Two powerful agronomic strategies, seed priming and seed fortification,have emerged as transformative tools to prepare seeds for the challenges of the modern world (Paparella *et al.,* 2015).

Seed priming and seed fortification are methods of seed treatment, which involves the application of biological, physical, or chemical agents (such as fungicides or insecticides) to seeds before planting to protect them from soil-borne diseases, pests, and environmental stresses (Mancini and Romanazzi, 2014). These technologies are transforming how we view seeds in agriculture, shifting the perspective from passive units that wait for favourable conditions to actively prepared biological systems capable of withstanding environmental stresses. This article reviews the science, methods, and practical applications of seed priming and seed fortification.

Seed Priming

Seed priming is the practice of soaking seeds in water or specific solutions for a defined period, followed by re-drying to the original moisture content before sowing. During the priming period, seeds undergo a series of biochemical and physiological changes collectively known as "pre-germinative metabolism". These include activation of DNA repair mechanisms, mobilisation of storage reserves, synthesis of protective proteins, and accumulation of osmolytes, all changes that prepare the seed for rapid and uniform germination once it is sown.

The concept was first systematically described by Hegarty (1978) and gained scientific momentum through the work of Parera and Cantliffe in the early 1990s. Today, seed priming is recognised as one of the most cost-effective and environmental friendly pre-sowing treatments available to farmers and seed companies.

At the cellular level, priming triggers the activation of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT) and ascorbate peroxidase (APX), which protect cellular components from reactive oxygen species (ROS) during imbibition and early germination. Priming also stimulates the expression of stress-responsive genes, including those encoding heat shock proteins (HSPs) and dehydrins, which confer a stress memory that allows seedlings to respond more effectively to future stresses, a phenomenon now described as priming-induced stress tolerance (Savvides *et al.,* 2016).

Types of Seed Priming

Several distinct priming methods have been developed, each suited to different crops, stresses, and farming contexts:

Hydropriming involves soaking seeds in distilled water. It is the simplest and most accessible method, particularly valuable in resource-limited farming systems. Studies on wheat (*Triticum aestivum*) and chickpea (*Cicer arietinum*) have shown that hydropriming can improve germination percentage by 15–30% under drought conditions.

Osmopriming (Osmoconditioning) uses solutions of salts (e.g., KNO_3, KH_2PO_4, NaCl) or organic osmolytes (e.g., polyethylene glycol, PEG) to control water potential during imbibition, ensuring a slow and regulated uptake. PEG-osmopriming at -1.0 to -1.5 MPa has been widely used in vegetable seeds, improving both germination uniformity and seedling vigour.

Hormonal priming involves pre-treatment of seeds with plant growth regulators such as gibberellins (GA_3), cytokinins, salicylic acid (SA), or brassinosteroids. Salicylic acid priming, in particular, has been shown to induce systemic resistance against both biotic and abiotic stresses through the activation of the phenylpropanoid pathway.

Biopriming is a biological approach in which seeds are inoculated with beneficial microorganisms, particularly plant growth-promoting rhizobacteria (PGPR) such as *Pseudomonas fluorescens, Bacillus subtilis,* and *Trichoderma spp*. These microbes colonize the spermosphere and rhizosphere, producing indole acetic acid (IAA), solubilizing phosphate, and secreting hydrolytic enzymes that enhance seedling establishment.

Thermopriming exposes seeds to mild heat stress (typically 35–40°C) before sowing, inducing the synthesis of HSPs and priming antioxidant systems. Research has demonstrated that thermoprimed seeds exhibit enhanced germination under both high and low-temperature extremes.

Redox priming uses redox-active compounds such as hydrogen peroxide (H_2O_2) at low concentrations to induce oxidative "eustress" (beneficial oxidative signalling), stimulating antioxidant defences and improving seedling vigour. Research in rice and maize has demonstrated significant improvements in shoot and root biomass following H_2O_2 priming.

Seed Fortification

While seed priming focuses on hydration-mediated metabolic activation, seed fortification takes a more direct approach: incorporating beneficial compounds into or onto the seed to supply the young seedling with resources it would otherwise have to scavenge from the soil. Seed fortification is thus a form of targeted seed enhancement that can address specific deficiencies like nutritional, biological, or environmental, right at the point of planting.

Nutrient Seed Fortification

Micronutrient deficiencies in soils are a global agricultural challenge. Zinc (Zn), iron (Fe), boron (B), molybdenum (Mo), and manganese (Mn) are among the most commonly deficient micronutrients in agricultural soils worldwide. Seed fortification with these elements ensures their immediate bioavailability to the germinating seedling, bypassing the slow and uncertain process of soil uptake. Slaton *et al.,* (2001) showed that soaking rice seeds in $ZnSO_4$ solution significantly improved seedling Zn concentration and early growth on Zn-deficient soils. Similarly, iron fortification through seed coating with Fe-EDTA chelates has been shown to improve seedling establishment in calcareous soils where Fe availability is limited by high pH. Boron seed treatment is especially critical in crops such as sunflower, rapeseed, and legumes, where B deficiency leads to poor pollen viability and reduced fruit set. Pre-sowing treatment with boric acid at 1–2 g L-1 has been shown to improve germination and pod formation under low-B conditions.

Hormonal and Bioactive Fortification

Seeds can also be fortified with phytohormones and other bioactive compounds that regulate plant development. Gibberellic acid (GA_3) fortification has been used to overcome dormancy in recalcitrant seeds and improve germination uniformity in aged seed lots. Ascorbic acid (Vitamin C) seed treatment has been shown to reduce oxidative damage during germination under salt and heavy metal stress, significantly improving root elongation and chlorophyll content in seedlings. Polyamines (putrescine, spermidine, spermine) are another class of bioactive compounds increasingly used in seed fortification. These small organic polycations stabilize membranes and nucleic acids under stress conditions and have been shown to improve germination and seedling establishment under osmotic and chilling stress in maize and tomato.

Nanoparticle-Based Seed Fortification

The emergence of nanoscience has opened a new frontier in seed technology. Nanoparticles (NPs) of metals and metal oxides including ZnO, TiO^2, Fe_3O_4 and carbon nanotubes have been applied as seed priming and fortification agents, with remarkable effects on germination, plant growth, and stress tolerance (Kah *et al.*, 2019).

Zinc oxide nanoparticles (ZnO-NPs) at concentrations of 10–100 mg L-1 have been shown to enhance germination, root elongation, and antioxidant enzyme activity in wheat and soybean (Ramesh *et al.*, 2014). TiO^2 nanoparticles have been reported to stimulate photosynthesis and nitrogen metabolism in spinach seedlings. The proposed mechanisms include enhanced water and nutrient uptake, ROS scavenging, and activation of stress-signalling pathways.However, the toxicological profile of nanoparticles at high concentrations is a legitimate concern, and regulatory frameworks for their agronomic use are still developing (Rico *et al.*, 2011). Research is actively ongoing to determine safe concentration thresholds, phytotoxic mechanisms, and the environmental fate of NPs in agricultural soils.

Conclusion

Seed priming and seed fortification represent two of the most scientifically sound, economically accessible, and environmentally responsible tools available to modern agriculture. By investing in the seed before it is sown, through metabolic activation, nutritional loading, biological inoculation, or nanotechnological enhancement, we can dramatically improve the reliability and productivity of crop establishment under a wide range of conditions.As climate change intensifies and the pressure on global food systems grows, these technologies become more important. The challenge now is to translate the wealth of laboratory and field research into scalable, farmer-friendly solutions that can be adopted widely, particularly in the developing world, where the vulnerability of rainfed agriculture to weather extremes is greatest. These approaches reduce the unpredictability of field establishment, conserve inputs by ensuring every seed counts, and equip the young seedling with the biological and nutritional advantage it needs to thrive under increasingly variable growing conditions. As precision agriculture continues to advance and the pressure on global food systems intensifies, the intelligent integration of priming and fortification technologies will be central to producing seeds that are not merely planted but purposefully prepared for optimal performance.

References

Hegarty, T. W. (1978). The physiology of seed hydration and dehydration, and the relation between water stress and the control of germination: A review. Plant, Cell & Environment, 1(2), 101–119.

Kah, M., Tufenkji, N., & White, J. C. (2019). Nano-enabled strategies to enhance crop nutrition and protection. Nature Nanotechnology, 14(6), 532–540.

Mancini, V. and Romanazzi, G., 2014. Seed treatments to control seedborne fungal pathogens of vegetable crops. Pest management science, 70(6), pp.860-868.

Paparella, S., Araújo, S. S., Rossi, G., Wijayasinghe, M., Carbonera, D., &Balestrazzi, A. (2015). Seed priming: state of the art and new perspectives. Plant Cell Reports, 34(8), 1281–1293.

Ramesh, M., Palanisamy, K., Babu, K., & Sharma, N. K. (2014). Effects of bulk and nano-titanium dioxide and zinc oxide on physio-agronomical characters of rice (Oryza sativa L.). Journal of Global Biosciences, 3(2), 415–422.

Rico, C. M., Majumdar, S., Duarte-Gardea, M., Peralta-Videa, J. R., & Gardea-Torresdey, J. L. (2011). Interaction of nanoparticles with edible plants and their possible implications in the food chain. Journal of Agricultural and Food Chemistry, 59(8), 3485–3498.

Savvides, A., Ali, S., Tester, M., & Fotopoulos, V. (2016). Chemical priming of plants against multiple abiotic stresses: mission possible? Trends in Plant Science, 21(4), 329–340.

Slaton, N. A., Wilson, C. E., Ntamatungiro, S., Norman, R. J., & Boothe, D. L. (2001). Evaluation of zinc seed treatments for rice. Agronomy Journal, 93(1), 152–157.

❖❖

ISSN No. 2583-3146

Seed Dormancy in Vegetable and Ornamental Genera: Classification, Causes and Control Strategies

Saklain Mulani*, Suchitra B and Neha A R

Department of Fruit Science, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram, Kerala

Corresponding Author: saklainmulani@gmail.com

Introduction

Seeds that fail to germinate under otherwise favorable environmental conditions are considered to be in a state of dormancy. Although many commercially available vegetable seeds are not subject to dormancy, dormancy issues can sometimes affect vegetable seeds. Seeds of some vegetable species/varieties may experience forms of secondary dormancy if exposed to stressful environmental conditions. Successful seed germination requires a fully developed seed with a healthy embryo and a store of food reserves, proper moisture and temperature conditions, and an appropriate oxygen concentration (soil aeration). For some plant species, the presence or absence of light may be required for germination to take place.[1] When a healthy seed cannot germinate in favorable environmental conditions, the seed is dormant or in a state of dormancy.[2] Plants use seed dormancy to help synchronize germination with seasons and favorable environmental conditions, and some plants use seed dormancy to allow for asynchronous germination over an extended period.[3]

Seed dormancy is an adaptive mechanism that controls the timing of germination. In some species, germination is synchronized through environmental signals, whereas in others it occurs in a staggered manner, facilitating the formation and persistence of a soil seed bank. Based on germination potential, seeds can be classified into three physiological states: (1) non-dormant seeds can germinate immediately under favorable conditions; (2) non-dormant, quiescent (inactive) seeds are inhibited from germinating by certain environmental factors; (3) dormant seeds do not germinate even when conditions are favorable. Seed dormancy can be a beneficial trait for plants in nature. For many vegetable species, seed dormancy traits have been minimized or eliminated through selection and breeding to promote rapid and uniform germination shortly after planting.[3] However, some vegetable species can still express seed dormancy traits that affect stand establishment and crop production (Table 1).[3,4,5]

Table 1: Dormancy Issues for Common Vegetables

Vegetable Crop	Dormancy Comments
Beet	Prewash treatment and drying at a maximum of 25°C may help

Vegetable Crop	Dormancy Comments
	break dormancy.
Broccoli, Brussels sprouts, cabbage, cauliflower	May require a period of dry storage to help break dormancy. KNO_3 and prechill treatments may help break dormancy.
Carrot	May require a period of dry storage to help break dormancy.
Celery	May exhibit secondary dormancy KNO_3, prechill, and light treatments may help break dormancy.
Cucumber	May require a period of dry storage to help break dormancy.
Lettuce	May exhibit secondary dormancy. May require a period of dry storage to help break dormancy. Prechill treatment may help break dormancy.
Onion	Prechill treatment may help break dormancy.
Pepper	May require a period of dry storage to help break dormancy KNO_3 treatment may help break dormancy.
Spinach	Prechill treatment may help break dormancy.
Tomato	May require a period of dry storage to help break dormancy. KNO_3 treatment may help break dormancy.

There are two basic types of seed dormancy, primary dormancy and secondary dormancy. Primary dormancy is an inherent state of a seed at the time that it is released/dispersed from the mother plant. Primary dormancy can result from exogenous factors (factors external to the embryo) such as a seed coat physically preventing a seed from absorbing water, inhibiting gas exchange, or preventing an embryo from expanding. Endogenous (within the embryo) factors, such as the presence of chemicals like abscisic acid, can prevent a seed from germinating, or the embryos can be immature at the time of release and require more time to fully develop.[2,3,6]

Secondary dormancy is induced in non-dormant seeds by environmental factors that are not favorable for germination after the seed has been released from the mother plant. Factors such as lack of oxygen, unfavourable temperatures, or the presence or absence of light (depending on the plant species), can induce secondary dormancy. Thermo-dormancy is a type of secondary.

Vegetable and flower genera containing seeds that have endogenous, non-deep physiological dormancy and require a period of dry storage (after-ripening) for germination.				Flower genera containing seeds that have endogenous, morphological dormancy.		
Alstromeria Antirrhinum Brassica Calendula Capsicum Celosia Cleome	Coreopsis Cosmos Cucumis Daucus Eschscholzia Festuca Gypsophilla	Helianthus Helichrysum Impatiens Lactuca Linum Lycopersicon Nicotiana	Oenothera Petunia Portulaca Solanum Viola	Anemone Apium Cyclamen Eryngium	Gentiana Hemerocallis Hosta Papaver	Primula Ranunculus Romneya

Effects of Temperature

Temperature can affect the germination of many plant species. Warm-season annuals (beans, cucumbers, tomatoes) may not germinate when temperatures are too low, while cool-season crops germinate best when temperatures are lower. This is not usually a result of seed dormancy but is related to the conditions favorable for germination. However, sometimes an aspect of dormancy may be involved. Some Brassica species have a cold temperature requirement that must be met before they will germinate.[1,6]. The seeds of some varieties of lettuce and onions are also susceptible to thermos dormancy, and they will become dormant if exposed to high temperatures, even after temperatures return to a favorable range.[3]

Effects of Light

The seeds of some plants require a certain amount of light before they can germinate, while other plants seed only germinate in the dark because their germination is inhibited by light.[5] As a result, planting depth can affect the germination of some crops because it affects the amount of light reaching the seed. For example, some varieties of lettuce require light to germinate, and planting these seeds too deeply may result in reduced germination.[6] In one study, freshly harvested lettuce seed required light to germinate, but germinated immediately after two days of imbibing water in the dark. After eight days of imbibition, the embryos did not germinate because of secondary dormancy, but secondary dormancy could be released by exposure to chilling and light.[3]

Effects of Moisture

Some vegetable crops have an endogenous type of dormancy related to seed moisture levels. These crops, including some varieties of Brassica (cole crops), Capsicum (pepper), Cucumis (cucurbits), Daucus (carrot), Lactuca (lettuce), and Solanum (tomato) require a period of dry storage after harvesting the seed before they will germinate uniformly.[3]

Other Stresses

Some species/varieties of Brassicas are susceptible to secondary dormancy following stressful conditions, including osmotic stress and low oxygen levels. The effects of these stress factors can also be influenced by temperature. In one study, higher rates of dormancy resulting from water stress were seen at 68°F (20°C) than at 54°F (12°C).[7]

Methods for Breaking Dormancy

Some seeds, such as those of some ornamental species, require procedures such as scarification (breaking or weakening the seed coat), removal of seed coats, and stratification (holding the seed at certain warm or cold temperatures to mimic over wintering or over-summering conditions) to break dormancy and allow germination. However, this is generally not needed for many commercial vegetable seeds. Some vegetable seeds may benefit from a short period of dry storage (by the seed company) to overcome some secondary forms of dormancy.[3,6] Vegetable seeds sold by seed companies are usually tested for germinat-ion rates under both optimal and stressful growing conditions to determine an expected germination rate for each lot of seeds. Short-term, on-farm seed storage conditions before seasonal planting, such as storage at high temperatures, may induce secondary dormancy in some varieties and result in lower-than-expected germination rates and stand establishment levels.

Table 2.Categories of seed dormancy in vegetable and flower seeds

Dormancy types	Causes of dormancy	Conditions to break dormancy	Representative species of flowers and vegetables
1. Exogenous dormancy			
Physical Chemical	Impermeable seed coat Inhibitors in seed coverings	Scarification Removal of seed coverings (fruits), leaching seeds	*Baptisia, Lathyrus* *Beta, Iris*
Mechanical	Seed coverings restrict radicle growth	Removal of seed covering, cold stratification	*Lactuca*
2. Endogenous dormancy			
Morphological	Embryo not fully developed at seed shed; small undifferentiated embryo	Warm or cold stratification	-
Rudimentary	Small undifferentiated embryo	Cold stratification and potassium nitrate	*Anemone, Ranunculus Daucus, Cyclamen*
Undeveloped	Small differentiated embryo (< size of seed)	Warm stratification and gibberellic acid	-
Physiological	Factors within embryo inhibit germination	-	-
Nondeep	Positively photoblastic, negatively photo dormant	Red light, darkness	*Lactuca, Primula, Cyclamen, Nigella*
	After-ripening	Short period of dry storage	*Cucumis, Impatiens*
Intermediate	Embryo germinates if separated from seed coat	Moderate periods (up to 8 weeks) of cold stratification	*Aconitum, Gentiana*
Deep	Embryo does not germinate when removed or forms physiological dwarf	Long periods (> 8 weeks) of cold stratification	*Dictamnus*
3.Combinational dormancy	Combinations of different dormancy conditions.	-	-

ISSN No. 2583-3146

Table 3. Vegetable and flower genera containing seeds that have endogenous, non-deep physiological dormancy and require light or darkness for germination.

Light (Light-requiring seeds)				Dark (Dark-requiring seeds)	
Amaranthus	Catharanthus	Gaillardia	Nicotiana	Allium	Nigella
Achillea	Capsicum	Gloxinia	Oenothera*	Cyclamen	Phacelia*
Alyssum	Celosia	Helenium	Petunia	Exacum	Schizanthus
Anagalis	Centranthus	Iberis	Platycodon	Nemophila	
Antirrhinum	Cleome	Impatiens	Portulaca		
Apium	Coreopsis	Kalanchoe	Primula		
Aquilegia	Cosmos	Lobelia	Ranunculus*		
Aster	Daucus	Lobularia	Salvia		
Begonia	Dianthus	Lactuca*	Silene		
Borago	Doronicum	Lychnis	Sinningia		
Browallia	Epilobium*	Lythrum	Viola		
Caladium	Eschscholtzia	Mimulus	Verbena		
Campanula	Eustoma	Monarda			

* *Indicate species with specific conditions or partial light/dark sensitivity.*

Table 4. Flower genera containing seeds that have endogenous, physiological dormancy and benefit from chilling stratification. Obligate species require stratification, while facultative species have seeds that will germinate without stratification but stratification increases germination rate.

Obligate			Facultative	
Aconitum	Dodecatheon*	Mertensia	Antirrhinum	Rudbeckia
Arum	Doronicum*	Penstemon	Aquilegia	Lobelia
Aruncus	Eranthis	Primula	Asclepias	Salvia
Aster	Gentiana	Pulsatilla	Delphinium	
Bergenia*	Helianthemum*	Thalictrum*	Echinacea	
Brodieia	Hemerocallis*	Tiarella*		
Chionodoxa	Hyacinthus	Tricyrtis		
Chrysopsis*	Lavandula	Trollius		
Dictamnus	Liatris	Tulipa		

* *Genera with seeds that are not dormant when freshly harvested but require treatment after a period of storage.*

Table 5. Flower genera containing seeds that have combinational dormancy. These species require a period of warm stratification for continued development of an immature embryo or to stimulate radicle growth and cold stratification for an endogenous, physiological dormancy prior to germination.

Warm followed by cold stratification			Cold followed by warm followed by cold stratification	
Actea*	Eryngium	Mertensia	Convallaria	Polygonatum*
Anemone	Helleborus	Sanguinaria*	Sanguinaria*	Smilacina
Asarum*	Jeffersonia	Trollius	Trillium*	

Warm followed by cold stratification			Cold followed by warm followed by cold stratification	
Cimicifuga* Eranthis Erythronium	Lilium* Paeonia* Polygonatum*	Tulipa		

* *Indicates genera with specific dormancy behavior (e.g., morphophysiological dormancy or requiring after-ripening before treatment).*

Conclusion

Seed dormancy is an important adaptive mechanism that regulates germination in vegetable and ornamental crops, but it can also hinder uniform seedling establishment and seed quality assessment. Different types of dormancy are influenced by factors such as seed coat structure, embryo development, temperature, light, moisture and storage conditions. Understanding dormancy mechanisms and applying suitable treatments such as scarification, stratification, after-ripening and chemical treatments are essential for improving germination and crop establishment. Effective dormancy management, therefore, plays a key role in successful seed production and sustainable cultivation practices.

References

DuPont, T. (2025). Seed and seedling biology. Penn State Extension. https://extension.psu.edu/*seed-and-seedling-biology*

Sami, A., Riaz, M., Zhou, X., Zhu, Z., & Zhou, K. (2019). Alleviating dormancy in *Brassica oleracea* seeds using NO and KAR1 through modulation of ethylene biosynthesis, ROS, and antioxidant enzymes. *BMC Plant Biology*, 19, 577.https://doi.org/10.1186/s12870-019-2118-y

Geneve, R. L. (1998). Seed dormancy in commercial vegetable and flower species. *Seed Technology*, 20(2), 236–250.https://www.jstor.org/stable/23433025

Awan, S., Footitt, S., & Finch-Savage, W. E. (2018). Interaction of maternal environment and allelic differences in seed vigor genes determines seed performance in *Brassica oleracea. The Plant Journal*, 94(6), 1098–1108.https://doi.org/10.1111/tpj.13922

International Seed Testing Association. (2024). *International rules for seed testing: Chapter 5—The germination test.*

Schalau, J. (2005). *Seed dormancy*. Arizona Cooperative Extension, Backyard Gardener.https://cales.arizona.edu/yavapai/anr/hort/byg/archive/seeddormancy.html

Momoh, E. J. J., Zhou, W., & Kristiansson, B. (2002). Variation in the development of secondary dormancy in oilseed rape genotypes under stress conditions. *Weed Research*, 42(6), 446–455.https://doi.org/10.1046/j.1365-3180.2002.00308.x

ISSN No. 2583-3146

Seed Treatment: The First Step to a Healthy Harvest

Suchitra B*, Saklain Mulani and Neha A R
Department of Fruit Science, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram, Kerala

Corresponding Author: suchitrabklm@gmail.com

Introduction

In agriculture, success begins with a tiny but powerful unit; the seed. No matter how advanced the farming techniques or how high-yielding the crop variety may be, the quality and health of the seed ultimately determine the success of cultivation. A healthy seed has the potential to produce vigorous seedlings, establish a strong crop stand, and contribute to higher productivity. However, farmers frequently encounter problems such as poor germination, weak seedlings, uneven crop growth, and reduced yields. These problems are often caused not by poor management practices, but by hidden infections, pest infestations, or physiological damage present within or on the surface of seeds. Many disease-causing organisms such as fungi, bacteria, viruses, and insects can survive on seeds and infect young plants immediately after sowing. During the early stages of growth, seeds and seedlings are highly vulnerable to environmental stresses and pathogen attacks. Therefore, protecting the seed at the beginning itself is essential for successful crop production.

Seed treatment has emerged as one of the simplest, most economical, and most effective methods to improve seed health and crop establishment. It is considered the first line of defensein crop protection because it safeguards seeds before they are planted in the field. By treating seeds prior to sowing, farmers can prevent many diseases and pest problems at an early stage, thereby reducing crop losses and ensuring better plant growth.

What is Seed Treatment?

Seed treatment refers to the application of physical, chemical, or biological agents to seeds before sowing in order to improve seed performance and protect the developing seedlings. The treatment may involve coating, soaking, dressing, or exposing seeds to specific conditions that help enhance germination and seedling establishment. Seed treatment protects seeds from seed-borne and soil-borne pathogens, insect pests and unfavorable environmental conditions during the crucial stages of germination and early growth (Paulikiene *et al.*, 2025).

Depending on the purpose, seed treatment may be carried out to:

- Control fungal, bacterial, and insect attacks
- Improve seed germination and vigour
- Break seed dormancy
- Enhance nutrient availability
- Promote rapid and uniform seedling emergence
- Increase tolerance to environmental stresses such as drought or salinity

Properly treated seeds generally germinate more uniformly, produce stronger root systems, and establish healthier crops.

Since the treatment is applied directly to the seed, only a small quantity of chemicals or biological agents is required, making the process economical and environmentally safer compared to large-scale field spraying.

Importance of Seed Treatment

Seeds often carry invisible threats such as fungal spores, bacteria, insect eggs, or nematodes that can damage crops even before they emerge from the soil. Infected or untreated seeds may rot in the soil, fail to germinate, or produce weak and unhealthy seedlings. Seed treatment helps eliminate or suppress these harmful organisms at the very beginning of crop growth, thereby ensuring better crop establishment and productivity. One of the major advantages of seed treatment is improved germination percentage and uniform crop stand. Treated seeds emerge more evenly and quickly, resulting in uniform plant growth throughout the field. This uniformity is important for efficient crop management, irrigation, fertilizer application, and harvesting.

Another significant benefit is enhanced seedling vigour. Seed treatments stimulate stronger and faster early growth, enabling seedlings to compete effectively for water, nutrients, sunlight, and space. Vigorous seedlings are also more capable of tolerating adverse environmental conditions and recovering from stress. Certain seed treatments help break seed dormancy and activate metabolic processes required for germination. Treatments such as scarification, stratification, or soaking improve water absorption and enzyme activity, leading to better and faster germination. Seed treatment also provides protection against soil-borne diseases during the early stages of crop growth when seedlings are highly susceptible. Since diseases are controlled at the seed stage itself, the need for repeated pesticide application in the field is reduced. This lowers production costs and minimizes environmental pollution. In addition, some modern seed coatings contain micronutrients, growth promoters, or beneficial microorganisms that improve nutrient uptake and stimulate plant growth. Biological seed treatments using beneficial microbes such as Trichoderma harzia num and Pseudomonas fluorescens not only suppress pathogens but also improve root development and plant health in an eco-friendly manner.

Certain seed treatments can also deter birds, rodents, and storage pests, thereby reducing seed loss after sowing. Further more, treated seeds often perform better under unfavorable conditions such as drought, low soil moisture, salinity, or temperature fluctuations, ensuring successful crop establishment even in challenging environments. Thus, seed treatment is an essential agricultural practice that improves seed health, enhances crop productivity, reduces dependence on pesticides, and supports sustainable farming systems.

Different Types of Seed Treatment

Seed treatment methods can be grouped into three main categories:

1. Physical Methods: Physical methods of seed treatment are non-chemical approaches used to enhance seed germination, break dormancy, improve seedling establishment, and manage seed-borne pathogens through treatments involving water, temperature, sunlight, and mechanical processes. Techniques such as hot water treatment, hot air treatment, solarization, scarification, stratification, and salt-water seed separation are widely used for improving seed health and vigor while maintaining seed viability (Pauli kiene *et al.*, 2025; Finch-Savage and Bassel, 2016).

- **Seed dip in water**: Soaking seeds in plain water at 20°C for 41 hours. Eg. Reduces loose smut infection in wheat.
- **Hot water treatment:** Seeds are dipped

in hot water (52°C) for 30 minutes. Effective for internally associated fungi and bacterial pathogens. Hot-water soaks will kill most seed borne fungi and bacteria without killing the seed, if properly used. The water temperature must be carefully controlled. A slight reduction in temperature may result in a failure to kill the fungi or bacteria. A slight increase may result in severe seed injury. Eg. Control black leg of cabbage and black rot of cabbage and cauliflower.

- **Hot air treatment:** Seeds are exposed to hot air stream for a specific period, which is safe for viability of seed. Effective for pathogens associated on seed surface.
- **Solar energy treatment:** Seeds are soaked in water for 6-8 hours.Expose the seeds to solar heat.Activated mycelium get destroyed without damaging seeds. Eg. Control loose smut of wheat.
- **Seed seeping:** It is a method used to remove infected, lightweight, or low-quality seeds especially those contaminated with pathogens or pests like nematodes. Seed seeping in 20% common salt. Eg. Eliminate lighter chaffy Karnal bunt infected seeds and nematode galls from wheat.
- **Seed Scarification:** It is a pre-germination technique used to break or weaken the hard outer seed coat to allow water and gases to enter, thereby initiating germination. It is commonly applied to seeds with physical dormancy caused by impermeable seed coats. Methods include mechanical abrasion, hot water soaking, or chemical treatment with acids.

- **Seed stratification:** It is a method of exposing soaked (imbibed) seeds to high or low temperatures for a period of time to break dormancy and improve germination.
  - a. **Warm Stratification:** Seeds are kept at 20–25°C (alternating) or 30°C (constant). Duration: 2 to 16 weeks (depends on species). **Purpose:** Breaks mechanical and morphological dormancy
  - b. **Cold Stratification:** Seeds are exposed to low temperatures. **Purpose:** Breaks physiological dormancy. Steps:Soak seeds in water. Pre-chill at 3–5°C for 48 hours. Drain water and store moist seeds at 3–5°C for the required period (species-specific)

2. Chemical Methods: Chemical seed treatment involves the application of chemical agents such as fungicides and insecticides to seeds in order to protect them from seed-borne and soil-borne pathogens, insects, and pests during germination and early seedling growth. These treatments improve seed health, enhance crop establishment, and reduce disease incidence in the field (Pauli kiene *et al.,* 2025).

Types of chemical seed treatment

Seed disinfection: Seed disinfection refers to the eradication of fungal spores that have become established within the seed coat, or more deep-seated tissues. For effective control, the fungicidal treatment must actually penetrate the seed in order to kill the fungus that is present.

Seed disinfestation: refers to the destruction of surface-borne organisms that have contaminated the seed surface. Chemical dips, soaks, fungicides applied as dust, slurry or liquid have been found successful. Eg:- Bacterial spot on chilli and tomato can be eliminated by dipping the seeds in bleaching powder solution.

Seed protection: the purpose is to protect the seed and young seedling from organisms in the soil which might otherwise cause decay of the seed before germination. Eg- Fungicides such as Thiram and Captan.

Common fungicides used for seed borne pathogens [Agarwal, V. K., & Sinclair, J. B. (1997)]

Fungicide	Type	Common Trade Name	Target Seed-Borne Pathogens/Diseases	Mode of Action
Thiram	Contact fungicide	Thiride	Damping-off, seed rot, smuts, seedling blight	Protects seed surface from fungal infection
Captan	Contact fungicide	Orthocide	Seed rot, damping-off, blights	Prevents fungal spore germination
Carbendazim	Systemic fungicide	Bavistin	Fusarium spp., anthr-acnose, wilt diseases	Inhibits fungal cell division
Carboxin	Systemic fungicide	Vitavax	Smuts, bunts, Rhizo-ctonia	Inhibits fungal respiration
Benomyl	Systemic fungicide	Benlate	Seed rot, blights, leaf spots	Disrupts fungal mitosis
Mancozeb	Contact fungicide	Dithane M-45	Broad-spectrum seed and soil-borne fungi	Multi-site enzyme inhibition
Metalaxyl	Systemic fungicide	Apron, Ridomil	Pythium, Phytophth-ora, downy mildew	Inhibits RNA synthesis in oomycetes
Oxycarboxin	Systemic fungicide	Plantvax	Rust diseases and seedling infections	Inhibits mitochondrial respiration
Propicon-azole	Systemic fungicide	Tilt	Smuts, rusts, seedling blights	Inhibits ergosterol biosynthesis
Ziram	Contact fungicide	Ziram	Seed decay and damping-off fungi	Enzyme inhibition in fungi

3. Biological Methods: Biological seed treatment involves the application of naturally derived active ingredients to seeds, which may include beneficial microbes such as fungi and bacteria, as well as plant-based or algal extracts. These biological agents are applied to seeds either in powdered or liquid form, ensuring a uniform coating across the entire seed surface. This uniform application ensures that the beneficial organisms or compounds are readily available to the seed at the time of germination and early growth, promoting better plant health and resilience against soil-borne pathogens and environmental stresses (Lamichhane *et al.*, 2022).

Trichoderma harzianum **(Fungus)**

Pseudomonas fluorescens **(Bacterium)**

Biological control of seed borne diseases [Agrios, G. N. (2005)]

Biological Control Agent	Type	Target Seed-Borne Pathogens/ Diseases	Mechanism of Action
Trichoderma harzianum	Fungus	*Fusarium, Rhizoctonia*, damping-off, seed rot	Mycoparasitism, competition, antifungal metabolites
Trichoderma viride	Fungus	Seedling blight, root rot, wilt pathogens	Produces enzymes and antibiotics against fungi
Pseudomonas fluorescens	Bacterium	*Fusarium, Pythium*, bacterial and fungal seed diseases	Antibiotic production and induced systemic resistance
Bacillus subtilis	Bacterium	Seed rot, damping-off, blights	Produces antimicrobial compounds and spores
Gliocladium virens	Fungus	*Rhizoctonia, Pythium*, damping-off	Competition and toxin production
Streptomyces griseoviridis	Actinomycete	Seed and soil-borne fungal pathogens	Antibiosis and root colonization
Agrobacterium radiobacter	Bacterium	Crown gall disease	Produces bacteriocins that suppress pathogens
Chaetomium globosum	Fungus	Seed rot and wilt pathogens	Antifungal metabolite production
Paenibacillus polymyxa	Bacterium	Damping-off and root diseases	Produces antibiotics and promotes plant growth
Coniothyrium minitans	Fungus	*Sclerotinia diseases*	Parasitizes fungal sclerotia

Advantages of Seed Treatment

Seed treatment offers several important advantages by improving seed health, enhancing germination and seedling vigor, protecting crops from pests and diseases, and ensuring better crop establishment and productivity under various environmental conditions.

1. Protection against seed and soil-borne pathogens and insects

Seed treatment protects germinating seeds and young seedlings from harmful fungi, bacteria, insects, and nematodes present either on the seed surface or in the soil. During the early stages of growth, seedlings are highly vulnerable to diseases such as damping-off, seed rot, smut, and blight. Treating seeds with fungicides, insecticides, or biological agents helps prevent these infections before they establish, ensuring healthy crop growth and reducing crop losses.

2. Enhancement of seed germination

Seed treatment improves the germination percentage and speed of germination. Certain treatments activate metabolic activities within the seed, improve water absorption, and help break seed dormancy. As a result, seeds germinate faster and more uniformly, leading to better crop establishment and improved field performance.

3. Early and uniform establishment of

seedlings

Treated seeds produce vigorous seedlings that emerge quickly and uniformly in the field. Uniform emergence results in better crop stand, synchronized growth and easier crop management practices such as irrigation, fertilizer application and harvesting. Early establishment also allows seedlings to compete effectively for nutrients, sunlight, and water.

4. Improved nodulation and nitrogen fixation in legumes

Biological seed treatment with beneficial microorganisms such as Rhizobium enhances root nodulation in legume crops. These bacteria form symbiotic associations with plant roots and convert atmospheric nitrogen into forms usable by plants. This improves nitrogen availability, promotes plant growth, reduces the need for chemical fertilizers, and increases soil fertility.

5. Efficient delivery of protection and nutrients

Seed treatment delivers fungicides, insecticides, micronutrients, or biofertilizers directly onto the seed surface where they are most needed. This targeted application reduces wastage of chemicals and nutrients and improves their efficiency compared to soil or foliar applications. Since only a small quantity of treatment material is required, it is economical and environmentally safer.

6. Uniform crop Stand Even Under Adverse Conditions

Seed treatment helps crops establish successfully even under unfavorable environmental conditions such as low moisture, excess moisture, salinity, or temperature stress. Treated seeds develop stronger root systems and better stress tolerance, enabling uniform crop growth even in difficult field conditions. This ultimately contributes to stable yield and improved productivity.

Conclusion

Seed treatment is a simple, economical, and highly effective practice that plays a crucial role in modern agriculture. By protecting seeds from seed-borne and soil-borne pathogens, insects and adverse environmental conditions, it ensures better germination, healthy seedling establishment, and improved crop productivity. Physical, chemical and biological seed treatment methods each contribute uniquely to enhancing seed quality and crop perfo-rmance. Among these, biological seed treatments are gaining greater importance due to their eco-friendly and sustainable nature. Overall, seed treatment not only reduces crop losses and minimizes excessive pesticide use but also supports sustainable farming and higher farm profitability. Therefore, adopting proper seed treatment practices is essential for achieving healthy crops, improved yields, and sustainable agricultural development.

Reference

Agarwal, V. K., & Sinclair, J. B. (1997). *Principles of seed pathology* (2nd ed.). CRC Press.

Agrios, G. N. (2005). *Plant pathology* (5th ed.). Elsevier Academic Press.

Finch-Savage, W.E. and Bassel, G.W., 2016. Seed vigour and crop establishment: extending performance beyond adaptation. *Journal of experimental botany,* 67(3), pp.567-591.

Lamichhane, J.R., Corrales, D.C. and Soltani, E., 2022. Biological seed treatm-ents promote crop establishment and yield: a global meta-analysis: Biological seed treatments promote crop establish-ment and yield: a global meta-analysis. *Agronomy for Sustainable Development,* 42(3), p.45.

Paulikiene, S., Benesevicius, D., Benesevic-iene, K. and Uksas, T., 2025. Seed treatment: Importance, application, impact, and opportunities for increas-ing sustainability. *Agronomy,* 15(7), p.1689.

ISSN No. 2583-3146

The Unseen Workforce: Pollinators as Key Drivers of Vegetable Production

Mangi Lal*, Y. D. Pawar, Monika and Krishan Yadav
Department of Vegetable Science, College of Horticulture, S. D. A. U., Jagudan
Corresponding Author: mangilalrawla21@gmail.com

Introduction

Since long back, the vegetable sector has emerged as an important component of Indian agriculture. Vegetables have high nutritional value and consume as food on daily basis contributed health security to the people. Vegetable production has made spectacular progress in recent years and touched a new height of supply and demand. India is the second largest producer of vegetables in the world after China, contributing about 14 per cent to the world's vegetable production. A significant section of small and marginal farming community, who constitute 80% of the country's farm holdings is significantly dependent on the production of vegetables such as various gourds, brinjal, cucumber, tomatoes apart from potatoes, onions etc. Vegetable crops constitute an essential component of human nutrition, providing vitamins, minerals, dietary fibre, antioxidants and bioactive compounds required for a balanced diet and food security. With increasing population pressure, changing dietary preferences and the need for nutritional security, enhancing vegetable productivity in a sustainable manner has become a major challenge for modern agriculture. Among the various factors influencing vegetable production, pollination is a critical biological process that directly affects fruit set, seed formation, yield and quality of many vegetable crops.

Pollination involves the transfer of pollen grains from the anther to the stigma, leading to fertilization and subsequent seed and fruit development. While some vegetable crops are self-pollinated or wind-pollinated, a substantial proportion depends on biotic pollination, primarily by insects. Crops such as cucurbits (cucumber, pumpkin, melon, gourds), solanaceous vegetables (tomato, brinjal, chilli), apiaceous crops (carrot, coriander, fennel), brassicas, and onion exhibit varying degrees of dependence on insect pollinators for optimum productivity. In these crops, effective pollination enhances not only yield but also improves fruit uniformity, size, shape, nutritional quality and seed viability.

Insect pollinators, particularly honey bees (Apis mellifera, A. cerana), bumblebees, solitary bees, flies, butterflies, beetles and wasps, play a dominant role in vegetable crop pollination. Honey bees are considered the most efficient pollinators due to their foraging behaviour, flower constancy and ability to visit a large number of flowers in a short time. Managed pollination through beekeeping has emerged as an effective strategy to improve vegetable yields, especially under protected cultivation and intensive cropping systems.

Pollination: Generally pollination is a process in which pollen are transfer from anther of the flower to the stigma of the same flower, other flower of the same plant and flower of other plant.

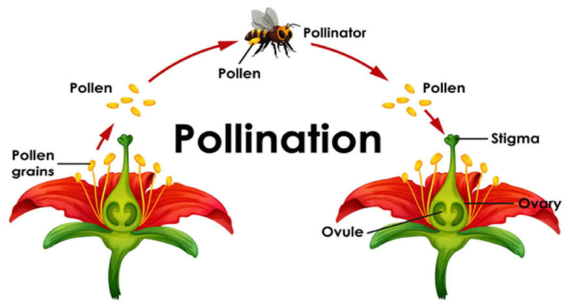
Pollinator: Pollens are unable to move self so they need a medium to transfer from one flower to the another flower these medium is known as pollinators. Pollinators may be insect, wind and water etc.

Why are pollinators important?

- Over a 70% of flowering plants require a pollinators to move pollens.
- In cross pollination, as combination of new characters occurs, so new varieties may be originated.
- Pollinators provide a fundamental ecosystem service that enable plants to produce fruits and seeds.
- Pollination helps in gene recombination.
- Cross pollination produces offspring with combination of characters from two types of varieties or races.

History of Pollination

- Camerarius (1694) was the first to demonstrated that pollination is essential for the production of seeds, which proved the existence of sexuality in plants.
- Sprengel (1750) Father of pollination. He recognized that the function of flower was attract insects and that nature favored cross- pollination.
- Prof. A. S. Atwal is considered the father of modern apiculture especially for introducing the high yielding Italian bee.
- Dr. G. P. Srivastava has conducted extensive research on the role of insects, particularly bees, in the pollinations of agricultural crops, contributing to the understanding of pollinator behavior and its impact on crop yields.
- Dr. P. K. Gupta An expert in horticulture, Dr. Gupta has conducted important research on the role of pollinators in vegetable production. His studied on the pollination requirements of crops like cucumbers, pumpkins and other gourds have provided valuable insights for farmers to optimize pollination and increase productivity.



Types of Pollination

Pollination is the transfer of pollen grains from the anther to the stigma of a flower, enabling fertilization and subsequent seed and fruit development. Based on the source of pollen and the pollinating agents involved, pollination in vegetable crops can be classified into the following types:

1. Self-pollination

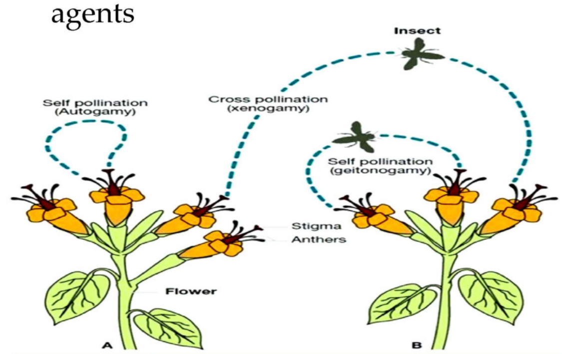
Self-pollination occurs when pollen is transferred from the anther to the stigma of the same flower or another flower on the same plant.Examples – Tomato, Pea, French bean, Cowpea, Lettuce etc.

Types of Self-pollination

- **Autogamy:** Pollination within the same flower.
- **Geitonogamy:** Pollination between different flowers of the same plant.

Characteristics

- Maintains genetic purity
- Requires minimal external pollinating agents



- Limited genetic variation

2. Cross-pollination

- Cross-pollination involves the transfer of pollen from the anther of one plant to the stigma of a flower on a different plant of the same species.Examples – Onion, Carrot, Cabbage, Cauliflower, Radish, Spinach etc.

Characteristics

- Promotes genetic diversity and hybrid vigour
- Often dependent on pollinating agents
- Enhances yield and quality in many vegetable crops

3. Often cross-pollination

In many self pollinating species, cross pollination may occur up to 5% or even reach to 30%, such species are referred as often cross pollinating species. Examples – Brinjal, okra, chilli etc.

Pollination Based on Pollinating Agents

A. Biotic Pollination

Pollination carried out by living organisms, mainly insects and, in some cases, birds.

1. Entomophily: "The pollination by insects"

The most important type of pollination in vegetable crops. It involves many species of honey bees viz. *Apis* cerana indica (Indian/Asian bee), *A. florea* (Dwarf or Red dwarf bee), *A. dorsata* (Giant bee), *A. andreniforms* (Black dwarf bee), *A. laboriosa* (Himalayan bee) and an introduced one *A. mellifera* (Western bee). In addition, several other pollinators including stingless bees, carpenter bees, bumble bees, butter fly etc. in several agro ecosystems. The vegetable crops pollinated entomophilously are Pumpkin, cucumber, bottle gourd, ridge gourd, carrot, radish, cabbage, knol-khol, cauliflower, onion etc.

Honey bees are the most important managed pollinators world wide because:

- Easily managed
- Easily transported
- Can be managed for other income
- Visit and pollinate a large number of crops

2. Chiropterophily: Pollens are transfer by bats. Ex.- Durian

3. Ornithophily: Pollens are transfer by birds. Ex- Banana and pineapple etc.

4. Malacophily: Pollens are transfer by snails. Ex- sweet potato and morning glory etc.

B. Abiotic Pollination

1. Anemophily: "The pollination by Wind"

Anemophilous pollen grains are light and non-sticky, so that they can be transported by air currents. Anemophilous plants possess well-exposed stamens so that the pollens are exposed to wind currents and also have large and feathery stigma to easily trap airborne pollen grains. The vegetable crops pollinated anemophilous are Beet, Spinach and Amaranthus, Palak etc.

2. Hydrophily

Rare in vegetable crops; pollen transfer occurs through water. Examples- Very limited (equatic plants) or absent in cultivated vegetables

Special Types of Pollination

A. Cleistogamy

Pollination occurs within unopened flowers, ensuring self-pollination. Example- Pea

B. Chasmogamy

Pollination occurs in open flowers, often involving insects. Examples- Cucurbits, Onion, Carrot etc.

Different pollinators which play vital role in Pollination
- Bees: 73%
- Flies: 19%
- Bats: 6.5%
- Wasp and beetels: 5%
- Birds and butterflies: 4%

Nesting site and Shelter
- When supporting populations of native bees, protecting or providing nest sites is as important as, if not more important than, providing flowers (Tschamtke *et al.*, 1998).

Bees: Solitary Bees (e.g., Mason Bees, Leafcutter Bees)
- **Nesting Sites:** Solitary bees often nest in small cavities.
- **Location:** Place nests in sunny, dry spots, sheltered from strong winds and rain, ideally facing southeast.
- Ground-Nesting Bees (Mining Bees, Bumblebees)
- **Nesting Sites:** Many ground-nesting bees prefer bare or sparsely vegetated ground. You can create small patches of bare soil in sunny areas.
- **Location:** Ensure the soil is well-drained and not compacted

Flies
- **Nesting Sites:** Some pollinating flies, like hoverflies, lay eggs in decaying organic matter or on plants infested with aphids (their larvae feed on them).
- **Shelter:** Flies need places to rest and hide. Ground cover plants, leaf litter, and dense plantings offer good shelters.

Beetles
- **Nesting Sites:** Beetles often lay their eggs in decaying wood or plant material. Leave dead wood and leaf litter in your garden to provide nesting sites.
- **Shelter:** Provide logs, rocks, and dense ground cover to offer beetles places to hide and over winter.

Humming bird
- **Nesting Sites:** Hummingbirds build tiny, cup-shaped nests on trees or shrubs.
- **Shelter:** Hummingbirds need sheltered spots to rest and hide from predators. Dense foliage and trees offer good protection.

Butter flies
- **Nesting Sites:** Butterflies lay their eggs on host plants specific to their caterpillar's diet.
- **Shelter:** Butterflies need places to roost and take shelter from bad weather. Shrubs, tall grasses, and dense foliage provide good hiding spots.

Moths
- **Nesting Sites:** Like butterflies, moths lay eggs on host plants. Provide a variety of native plants to support different species.
- **Shelter:** Moths need dark, sheltered areas during the day. Dense foliage, trees, and even bat houses can provide daytime shelter.

Methods of integrated management of pollination in vegetable crops:

1. Follow planting guidelines for your time zone: Planting time of any crop should be right like cucurbits are generally warm season crops they cannot pollinate in winter season.

2. Minimize stress: Maintain minimum stress in field by proper spacing, time to time watering, weeding and control of pest disease to reduce stress.

3. Fertilize properly: Avoid use of excess nitrogenous fertilizer because nitrogen fertilizer promotes vegetative growth and reduce formation of blossom.

4. Encourage pollinators: Attract more and more pollinators in field to add extra flower crop those are favors by bee.

5. Use pesticides with caution: Avoid use of pesticide and chemical in field between

9:00 AM to 4:00 PM because this time bee are more active in field.

Benefits of effective management of pollinations in field

1. Ecological Benefits
2. Environmental
3. Increased Yield
4. Increased Quality
5. Economic Impact
6. Breaks Incompatibity

Improper Pollination in Vegetable Crops: Improper pollinations in vegetables create many problems those are directly related to fruits like flower poor fruit setting, misshapen fruits and rotting of fruit and these problems are directly reduce the marketing yield as well as quality of fruits.

Harmful Pollinators: Some insects are help to pollinate to plant but also harmful for same plants is known as harmful pollinators.

1. **Moths and Butterflies:** The larvae of the cabbage butterfly (*Pieris rapae*) are major pests of cruciferous vegetables like cabbage, broccoli, and kale, causing extensive leaf damage.
2. **Colorado potato beetle:** Colorado potato beetle (*Leptinotarsa decemlineata*) can pollinate some plants but their larvae and adults feed on the foliage of crops like potatoes, tomatoes, and eggplants.
3. **Thrips:** Many species are also pests that feed on vegetable plants, causing damage to leaves, flowers, and fruits. They can also transmit plant viruses.
4. **Cucumber Beetles:** Their larvae feed on roots, and adults can damage leaves, stems, and fruits, spreading bacterial wilt and mosaic virus, which can severely affect crop yields.

Farming Practices help to attract more pollinators in field

- Cover crops
- Maintain uncultivated land along field margins
- Roadside Management
- Annual cropping systems
- Resistant varieties

Enhancing pollination efficiency

- **Identify Pollination Requirements**
  - Understand which pollinators are most effective for your specific vegetable crops.
  - Determine the flowering period and the pollination needs of the crops.
- **Select Appropriate Managed Pollinators**
  - Choose the type of managed pollinator that is best suited for the crop and growing conditions.
- **Prepare the Environment**
  - Ensure the growing environment is conducive to the health and activity of the managed pollinators.
  - Provide supplementary food sources if necessary (e.g., additional flowering plants).
- **Introduce the Pollinators**
  - Follow best practices for introducing and maintaining the pollinator populations.
- **Monitor and Maintain**
  - Regularly monitor pollinator activity and crop pollination success.
  - Make adjustments as needed to maintain effective pollination.

Techniques for the promoting natural pollination

- Planting Pollinator-friendly Flowers
- Providing Nesting Sites
- Maintaining Hedgerows and Borders
- Reducing Pesticide Use
- Implementing Companion Planting
- Scheduling Crop Planting for Continuous Bloom

Threats to pollinators populations

1. Habitat Loss and Fragmentation
2. Invasive Species
3. Climate Change

4. Socioeconomic Factors
5. Lack of floral resources
6. Pesticides and Chemicals
7. Diseases and Parasites
8. Pollution

IPM to Minimize Risks to Pollinators

How to use pesticides and chemicals?

Use liquid sprays and granules instead of dusts: Clean up spilled granules. Avoid use of micro- encapsulated pesticides that are similar in size to pollen and can be collected by pollinators and mistaken as food.

Use vegetative buffer zones (grass or hedgerow of shrubs): between areas of pesticide application and pollinator habitats to reduce pesticide drift.

Applicators apply insecticides to fruit or vegetables when pollinators are not present.

Some other solution to control insect and pest as IPM

1. Cultural Controls: We can follow cultural method like, crop rotation, tillage, timely weeding and trap crop.

2. Biological Controls: Use some beneficial insect to control harmful insects in field, Trichograma and BT.

3. Mechanical Controls: We can remove insect by hand picking and by use of different trap for different insect.

4. Chemical Controls (Pesticides): use some pesticide and chemical with proper cautions.

5. Habitat Management: Change the environment of main field to attract more beneficial insect in field to kill harmful insect.

6. Education & Collaboration: Education means we need to aware and know about how to control particular insects and collaboration means participation between among group of peoples to control insect on large scale.

India's First Pollinator Habitat Restoration Kit

The ICAR-Directorate of Floricultural Research, Pune, has developed the Pollinator Habitat Restoration Kit India's first comprehensive package designed to support insect pollinators in agricultural ecosystems.

The Pollinator Habitat Restoration Kit includes

- Seeds of 20 carefully selected seasonal flowering species
- A bilingual (Hindi and English) booklet with agro-ecological information and pollinator-friendly farming guidelines
- A QR-coded card providing plant care tips, insights into floral rewards, and digital access to the pollinator database.

Conclusion

Pollinators are an essential yet often overlooked component of vegetable production systems. By enabling the successful pollination of many vegetable crops, they improve fruit set, seed production, crop quality and overall yields, while also supporting biodiversity and ecosystem health. Despite their immense contribution, pollinator populations are increasingly threatened by habitat loss, pesticide use, climate change, and environmental degradation. Protecting these vital organisms requires sustainable agricultural practices, conservation of natural habitats, reduced reliance on harmful chemicals, and increased awareness among farmers, researchers, and policymakers. Recognizing pollinators as an indispensable "unseen workforce" is fundamental to ensuring resilient food systems, enhancing agricultural productivity, and securing global food and nutritional security for future generations.

ISSN No. 2583-3146

Extreme Weather Events and their Impact on Kharif Crops in Mewar Region of Rajasthan

Arvind Swami*, Valenta Kangjam and Anubhav Galav

Department of Agriculture, College of Agriculture and Veterinary Science, Mewar University, Gangrar, Chittorgarh

Corresponding Author: anubhavglv@gmail.com

Introduction

Mewar region of Rajasthan comprises Udaipur, Rajsamand, Chittorgarh, Pratapgarh and parts of Bhilwara districts, falling under Agro-climatic Zone IV a Sub-humid Southern Plain. The region receives 650–900 mm annual rainfall, 85–90% of which occurs during June –September. Kharif crops collectively with maize, soybean, groundnut, black gram and sorghum occupy >70% of the gross cropped area. During 1991–2024, the frequency of extreme weather events in Mewar has shown an increasing trend as per IMD gridded data. These events include dry spells, high intensity rainfall, heat waves during grain filling, and unseasonal rainfall at maturity. Such events directly affect crop establishment, growth, and final yield. This review compiles published work on extreme weather trends and their documented impact on major Kharif crops of Mewar.

Extreme Weather Events in Mewar: Trends and Characteristics

Rainfall Extremes

Analysis of IMD 0.25°×0.25° daily rainfall for Mewar shows that the number of very heavy rainfall days >124.4 mm day^{-1} increased from 0.8 days $year^{-1}$ during 1971–2000 to 1.4 days $year^{-1}$ during 2001–2020. Simultaneously, the maximum duration of dry spells within monsoon increased from 12 days to 17 days. Basamma et al. 2017 reported that short-term droughts using SPI^{-3} occur once in 3 years in Udaipur district, with 2014 and 2015 being severe drought years.

Temperature Extremes

Praveen et al., 2020 using IMD 1° data reported a significant rise of 0.9°C in maximum temperature during July – August over southern Rajasthan since 1980. Heat wave days with Tmax >40°C during September, coinciding with grain filling of maize and soybean, have increased from 2.1 to 4.6 days $decade^{-1}$.

Indices Used for Analysis

Most studies for Mewar used ETCCDI indices: CDD Consecutive Dry Days R95p Rainfall from very wet days, TXx Monthly max Tmax, and WSDI Warm Spell Duration Index. These were computed using RClimDex and ClimPACT2 software on IMD data.

Impact on Major Kharif Crops

Maize Zea mays L

Maize is the principal Kharif cereal covering 2.1 lakh ha in Mewar. Dry spells >10 days at tasseling stage reduce yield by 25 – 40% due to poor pollination. Jat *et al.*, 2018 recorded that each day of Tmax >38°C during grain filling reduced maize yield by 120 kg ha^{-1} in Udaipur. High intensity storms in August 2006 and 2019 caused waterlogging and 60–80% crop lodging.

Soybean Glycine max L

Soybean area has expanded to 1.8 lakh ha. The crop is sensitive to both drought and excess rain. Rathore et al. 2015 found that a 15-day dry spell at pod development reduced pods plant^{-1} from 42 to 26. Conversely, >200 mm rain in 3 days during September 2011 caused pod rot and 35% yield loss. High night temperature >24°C during seed filling reduces oil content by 1.5 – 2%.

Groundnut Arachis hypogaea L.

Groundnut in Chittorgarh and Pratapgarh suffers from mid-season drought. Studies by CAZRI show that CDD >20 days reduces pod yield by 45% due to peg failure. Terminal heat stress in late September causes shriveled kernels and lowers shelling%.

Pulses: Black Gram and Green Gram

Pulses are grown on sloppy marginal lands. Rainless period of 12 days at flowering causes 50–70% flower drop. Unseasonal rain at harvest causes 100% loss due to sprouting in pods, as observed in 2022.

Adaptation and Mitigation Research in Mewar

Varieties: Short duration maize hybrids Pratap-5, soybean RKS-45, and drought tolerant groundnut Pratap Raj Mungphali-1 released by MPUAT showed 15–20% higher yield under dry spells.

Agronomic: Ridge - furrow planting + mulching conser-ved 25 mm extra moisture and reduced impact of 18-day dry spell in AICRPDA trials. Weather Services: GKMS Udaipur issues 5-day forecast + Agro met Advisory. Adoption reduced losses by 12–18% as per NCMRWF survey.

Insurance: PMFBY covers localized catastrophe. Claim ratio for Mewar was highest in 2015 drought and 2019 excess rain years.

Conclusion

Extreme rainfall and temperature events in Mewar have increased in the last 30 years and directly influence Kharif crop stability. Dry spells at reproductive stage and high intensity rainfall are the two major hazards. Location-specific varieties, in-situ moisture conservation, and timely agromet advisories are effective but need scaling. Future work should focus on developing a Mewar-specific climate risk index and evaluating crop models under future climate scenarios using CMIP6 data.

References

Basamma, K.A., Purohit, R.C., Bhakar, S.R., Kothari, M., Joshi, R.R., Sharma, D., Singh, P.K., and Mittal, H.K. 2017. Analysis of Short-Term Droughts in the Mewar Region of Rajasthan by Standard Precipitation Index. Int. J. Curr. Microbiol. App. Sci. 6 (6): 182-192. https://doi.org/10.20546/ijcmas.2017.606.022

Praveen, B., Talukdar, S., Shahfahad, Somani, S., Praveen, A., Mondal, A., Douod, M., Kim, S. & Rahman, A. 2020. Innovative trend analysis of annual and seasonal rainfall and temperature in India. Atmospheric Research 231: 104665. https://doi.org/10.1016/j.atmosres. 104665

Jat, S.L., Parihar, C.M., Singh, A.K., Kumar., B., Singh, D., Jat, M. L. & Yadav, O.P. 2018. Climate resilient maize systems for Mewar region. Maize Journal. 72: 45-52.

Rathore, B.S., Solanki, N.S., and Sharma, S.K. 2015. Effect of weather parameters on soybean productivity in southern Rajasthan. Journal of Agrometeorol. 17(1): 89-93.

IMD. 2023. Annual Climate Summary 2022. India Meteorological Department, Pune.

Central Arid Zone Research Institute. 2019. Trends and homogeneity of rainfall over arid Rajasthan. Theor. Appl. Climatol. 137: 1155–1168.

ISSN No. 2583-3146

Climate-Smart Horticulture: Securing Fruit and Vegetable Production Under Climate Change

Soustav Datta[1]* and Monami Sarkar[2]

[1]Rathindra Krishi Vigyan Kendra, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, Birbhum, West Bengal

[2]Department of Vegetable Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal

Corresponding Author: sodpurarunachal@gmail.com

Introduction

Climate change has emerged as one of the greatest challenges to global horticulture and food security (IPCC, 2022). Rising temperatures, erratic rainfall, droughts, floods, cyclones, heat waves and increasing pest and disease outbreaks are significantly affecting the production of fruits and vegetables worldwide. Horticultural crops are highly sensitive to environmental changes because of their delicate growth habits, high water requirements and susceptibility to temperature fluctuations. As a result, climate change threatens both the productivity and quality of horticultural produce.

In this context, Climate-Smart Horticulture (CSH) has become an essential approach for ensuring sustainable fruit and vegetable production. Climate-smart horticulture refers to the adoption of innovative, resilient and environmentally sustainable horticultural practices that help farmers adapt to climate change, improve productivity and reduce greenhouse gas emissions (Lipper *et al.*, 2014). Horticulture plays a critical role in nutritional security, employment generation, income enhancement and ecological sustainability. Therefore, securing fruit and vegetable production under changing climatic conditions is vital for the future of horticulture as well as human health.

Climate change and its impact on horticulture

Horticultural crops are highly vulnerable to climatic stresses because their growth, flowering, fruit setting, ripening and quality depend greatly on temperature, humidity, rainfall and soil moisture.

1. Rising temperature

Increased temperatures directly affect physiological processes in horticultural crops. Excessive heat causes flower drop, poor fruit setting, sunburn, reduced pollination and shortened crop duration. Many fruit crops such as apple, pear, peach and cherry require chilling hours during winter. Rising temperatures also reduce chilling accumulation, leading to poor flowering and reduced yields (Hatfield and Prueger, 2015). Vegetable crops like tomato, cauliflower, cabbage and lettuce are also **highly sensitive to heat stress.**

2. Irregular rainfall and water scarcity

Unpredictable rainfall patterns and prolonged droughts reduce soil moisture availability and irrigation water resources. Water stress leads to poor germination, stunted growth, fruit cracking, blossom end rot and yield reduction. On the other hand, excessive rainfall and flooding cause waterlogging, root rot, nutrient leaching and increased disease incidence in crops like onion, potato and cucurbits.

3. Increased pest and disease incidence

Climate change creates favourable conditions for the rapid multiplication and spread of insect pests, pathogens and weeds. Warmer temperatures and humidity increase the incidence of fruit flies, aphids, mites, fungal diseases, bacterial wilt and viral infections. The emergence of new pests and diseases in previously unaffected regions has become a serious concern for horticultural production systems.

4. Post-harvest losses

Climate change also affects storage, transportation and market infrastructure. High temperatures and humidity increase spoilage and post-harvest losses in fruits and vegetables, especially in tropical regions.

Concept of climate-smart horticulture

Climate-smart horticulture integrates sustainable production technologies, resource conservation practices, resilient crop varieties and modern management strategies to cope with climate variability.

The approach focuses on:

1. Increasing horticultural productivity and farmer income: The main objective of climate-smart horticulture is to increase productivity and improve the income of farmers without causing environmental damage. It focuses on producing more fruits and vegetables using fewer natural resources such as water, energy and land.

2. Enhancing resilience and adaptation to climate change: Farmers are increasingly facing droughts, floods, heat waves, salinity and pest outbreaks. Climate-smart technologies help crops survive these stresses through the use of stress-tolerant varieties, protected cultivation, efficient irrigation systems and diversified farming systems. These practices reduce crop failure risks and improve the ability of farming systems to withstand climatic shocks.

3. Reducing greenhouse gas emissions and environmental degradation: Excessive use of fertilizers, pesticides and improper land management practices contribute to environmental pollution and climate change. Climate-smart practices encourage the use of renewable resources, organic inputs and carbon sequestration methods that reduce the environmental footprint of horticultural production.

Principles of climate-smart horticulture

1. Efficient resource management

Efficient management of natural resources is one of the most important principles of climate-smart horticulture. Natural resources such as water, soil, nutrients, energy and land are becoming increasingly limited due to climate change and population growth. Therefore, it is essential to use these resources carefully and efficiently to maintain sustainable horticultural production. Climate-smart horticulture promotes the use of efficient irrigation systems such as drip irrigation and micro-irrigation, which supply water directly to the root zone of plants (FAO, 2017). Fertigation technology, where fertilizers are applied through irrigation systems, ensures precise nutrient delivery and reduces nutrient loss. Mulching is another important practice that conserves soil moisture, controls weeds and regulates soil temperature. Protected cultivation structures such as greenhouses and polyhouses further optimize the use of water, nutrients and energy by creating controlled growing environments.

2. Resilience building

Resilience building refers to strengthening the ability of horticultural production systems to withstand and recover from climatic stresses such as droughts, floods, storms, heat waves and pest outbreaks. Crop diversification is one of the most effective resilience-building strategies. Integrated farming systems that combine horticulture with livestock, fisheries or poultry also increase farm resilience and provide multiple sources of income. Heat-tolerant, drought-tolerant, flood-resistant and salinity-tolerant varieties are better able to survive under extreme climatic conditions.

3. Environmental sustainability

Environmental sustainability is a major principle of climate-smart horticulture as it promotes environmentally friendly farming practices that minimize ecological damage while maintaining productivity. Climate-smart practices encourage integrated nutrient management, organic farming, biofertilizers and integrated pest management to reduce chemical use. Soil conservation practices such as cover cropping, conservation tillage, mulching and contour farming help prevent soil erosion and maintain soil fertility. Carbon sequestration is another important component of environmental sustainability. Fruit orchards, agroforestry systems and healthy soils absorb and store carbon dioxide from the atmosphere, thereby helping mitigate climate change.

4. Adoption of modern technologies

Modern technologies play a crucial role in improving the efficiency, productivity and resilience of horticultural systems under changing climatic conditions. Climate-smart horticulture encourages the use of advanced scientific tools and digital technologies for better farm management. Precision farming technologies such as GPS, drones, remote sensing and sensors help farmers monitor crop growth, soil moisture, nutrient levels and pest incidence accurately. Weather forecasting and climate advisory services provide farmers with timely information about rainfall, temperature, humidity, storms and drought conditions. Artificial intelligence and digital agriculture are also emerging as important tools in climate-smart horticulture. Emerging technologies such as hydroponics, aeroponics and vertical farming are expected to transform horticultural production in the future.

Role of biotechnology in climate-smart horticulture

Biotechnology plays a major role in developing climate-resilient horticultural production systems (Tester and Langridge, 2010). One important contribution of biotechnology is the development of stress-tolerant crop varieties through advanced breeding techniques. Marker-assisted breeding allows scientists to identify and transfer desirable traits more efficiently than conventional breeding methods. Genetic engineering also enables the development of crops with improved resistance to pests, diseases, and environmental stresses. Tissue culture and micropropagation are widely used for the rapid multiplication of disease-free planting materials.

Conclusion

Climate change poses serious threats to fruit and vegetable production worldwide. Rising temperatures, erratic rainfall, water scarcity, pest outbreaks and soil degradation are reducing horticultural productivity and quality. Climate-smart horticulture offers a sustainable solution by integrating adaptation, mitigation and productivity enhancement strategies. Practices such as climate-resilient varieties, efficient irrigation, protected cultivation, integrated pest management, agroforestry, precision horticulture and improved post-harvest management can significantly strengthen the resilience of horticultural systems. Climate-smart horticulture not only secures food and nutritional security but also contributes to environmental sustainability, carbon sequestration and rural livelihood improvement. Therefore, promoting climate-smart horticulture is essential for building resilient agricultural systems and ensuring sustainable fruit and vegetable production under changing climatic conditions.

Reference

Food and Agriculture Organization of the United Nations (2017). *Climate-smart agriculture case studies 2017.* Food and Agriculture Organization of the United Nations.

Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes, 10, 4-10.*

Intergovernmental Panel on Climate Change (2022). *Climate change 2022: Impacts, adaptation and vulnerability.* Cambridge University Press.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., ... & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature climate change, 4(12), 1068-1072.*

Tester, M., & Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. Science, 327(5967), 818-822.

ISSN No. 2583-3146

Unravelling Virus–Vector Interactions in Okra: Molecular Characterization and Integrated Management of Begomovirus Diseases

Subhangi Basu[1*], Asit Kumar Mandal[2] and Arup Chattopadhyay[3]

[1&3]Department of Vegetable Science, [2]Department of Plant Pathology
Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal

Corresponding Author: basu2000subhangi@gmail.com

Introduction

Okra [*Abelmoschus esculentus* (L.) Moench], belonging to the family Malvaceae, is believed to have originated in tropical Africa and is extensively cultivated throughout tropical and subtropical regions of the world (Ali *et al*., 2012). It is one of the most important vegetable crops grown in India during both summer and rainy seasons owing to its high nutritional value, consumer preference, wide adaptability and export trade. India occupies the leading position in global okra production, contributing nearly 70.00 % of the world's total output. Significant cultivation is spearheaded by Gujrat (Saurashtra-Kutch region), West Bengal, Madhya Pradesh, Bihar, and Andhra Pradesh. The United Kingdom, Germany, and North America remain the strongest international markets for Indian okra, with buyers highly satisfied with pod quality.

Production threat

Despite its economic importance, okra productivity in tropical regions remains considerably low due to the prevalence of several abiotic and biotic stresses (Jellis, 2009). Among the biotic constraints, *Bhendi Yellow Vein Mosaic Virus* (BYVMV) and *Okra Enation Leaf Curl Virus* (OELCV), both caused by begomoviruses, are regarded as the most destructive diseases limiting okra production. These viral diseases are capable of causing yield losses of up to 94% and 100%, respectively, in susceptible varieties and hybrids (Sastry and Singh, 1974; Venkataravanappa *et al.*, 2013). The persistent stagnation in okra productivity over the past few decades has largely been attributed to the lack of durable resistant cultivars coupled with poor availability of quality seed material.

Although the virus is not transmitted through seed (Givord and Koenig, 1974), its rapid dissemination occurs through whitefly-transmitted begomoviruses, primarily vectored by *Bemisia tabaci* (Venkataravanappa *et al.*, 2014). In the Gangetic plains of eastern India, whitefly populations remain highly active during the morning hours between July and September, thereby facilitating rapid disease spread (Seth *et al.*, 2016). At present, BYVMV and OELCV occur in almost all major okra-growing states of India, often assuming epidemic proportions and posing a serious threat to sustainable okra cultivation. Furthermore, resistance breakdown has frequently been reported in several commercially popular cultivars, including Parbhani Kranti, P-7, Arka Anamika, Arka Abhay, Pusa A-4, Hisar Unnat and Kashi Pragati etc. (Sanwal *et al.*, 2014).

Virus–Vector relationship

The extensive genetic diversity and mixed infection patterns among begomoviruses facilitate recombination and pseudo-recombination events, resulting in the emergence of novel and highly virulent strains. Recombination has played a crucial role in the evolution of geminiviruses (Seal *et al.*, 2006), including the origin of OELCV, which is believed to have evolved through sequence exchange among several malvaceous begomoviruses such as *Cotton Leaf Curl Bangaluru Virus* (CLCuBaV), *Mesta Yellow Vein Mosaic Virus* (MeYVMV), and BYVMV (Venkataravanappa *et al.*, 2015). Additionally, OELCV has been reported in association with two distinct betasatellites, namely Bhendi Yellow Vein Betasatellite (BYVB) and Okra Leaf Curl Betasatellite (OLCuB) (Venkataravanappa *et al.*, 2015). The emergence of the polyphagous "B" biotype of Bemisia tabaci, combined with mixed cropping systems and the extensive host range of over 600 plant species, has further enhanced the spread and adaptability of geminiviruses to previously unaffected hosts (Singh *et al.*, 2013). Recent reports indicate that most available commercial varieties and hybrids exhibit high susceptibility to BYVMV, which is transmitted semi-persistently by cryptic whitefly species that are morphologically similar but genetically distinct (Sanwal *et al.*, 2014; Khatun *et al.*, 2020). In the Gangetic plains of eastern India, recognized as a hotspot for viral incidence, infection occurs across all phenological stages of crop growth (Jamir *et al.*, 2020). The Bemisia tabaci cryptic species, previously considered less resistant than the MED type (Mediterranean cryptic species, formerly known as the Q biotype), has recently exhibited enhanced insecticide resistance due to sustained selection pressure and interpopulation gene flow (Luo *et al.*, 2010). Cytochrome P450 monooxygenases, parti-cularly CYP6DB3, have been implicated in resistance to neonicotinoids such as imidacloprid and thiamethoxam in the *Bemisia tabaci* biotype, and similar detoxification mechanisms are presumed in MEAM1(Middle East Asia Minor 1) populations (Wei *et al.*, 2023).

BYVMV disease

OELCV disease

Genetic complexity

Several studies have highlighted the importance of understanding the cytological behaviour and genetic stability of natural and induced amphidiploids utilized in okra breeding programmes. The ploidy level of breeding materials profoundly influences inheritance patterns, breeding behaviour, and heritability of economically important traits. However, the effective exploitation of genetic variability in okra remains constrained by limited molecular markers, the lack of saturated linkage maps, and insufficient genomic resources (Sanwal *et al.*, 2014). Genetic analysis in okra is further complicated by its highly polyploid and complex genome, with chromosome numbers ranging from 2n = 56 to 200 and an estimated genome size of approximately 16,000 Mb distributed across 65 linkage groups. Cytogenetic studies have demonstrated that 36 chromosomes of cultivated okra share homology with *Abelmoschus ficulneus*, while 29 chromosomes exhibit complete homology with *Abelmoschus tuberculatus*, supporting the amphidiploid origin of cultivated okra (29TC + 36Y). Owing to its extensive polyploidy and large number of linkage groups, okra is regarded as one of the most genetically complex crop species after wheat (Sanwal *et al.,* 2014).

Integrated management protocol

To address the increasing challenge of insecticide resistance in whitefly populations, the implementation of integrated pest management (IPM) strategies is essential for achieving sustainable and long-term suppression of the vector. Such strategies include the judicious rotation of insecticides with different modes of action, integration of biological control agents such as parasitoids, predators, and entomopathogenic fungi, as well as the adoption of cultural practices including removal of alternate hosts, use of healthy seeds, crop sanitation, adjustment of sowing dates, and deployment of resistant cultivars. These approaches collectively reduce selection pressure on vector populations and delay the evolution of resistance in Bemisia tabaci.

A comprehensive field investigation conducted during 2020–2022 in the Gangetic plains of West Bengal evaluated an integrated pest and disease management module for effective suppression of BYVMV disease and its whitefly vector, *Bemisia tabaci*, in okra. The technology was developed considering the increasing problem of insecticide resistance, environmental contamination, and declining efficacy of sole chemical-based approaches under intensive okra cultivation systems.

The module consisted of a combination of cultural, physical, chemical, and botanical approaches aimed at reducing vector population build-up and minimizing virus transmission throughout the crop growth period. Two rows of maize were sown as a border crop 25–30 days prior to sowing of okra to act as a physical barrier against incoming whitefly populations and to disrupt vector movement into the crop ecosystem. The border crop also helped in reducing the initial inoculum pressure and served as an ecological barrier for virus spread.

Silver-black reflective polyethylene mulch (Agrimulch, 25 μm thickness) was applied immediately before sowing of okra seeds to repel whiteflies through reflection of ultraviolet and visible light, thereby interfering with host-finding behaviour of the vector. The mulch additionally conserved soil moisture, suppressed weed growth, moderated soil temperature, reduced evaporation losses and improved overall crop vigour. Seeds were treated with thiamethoxam 30% FS @ 4 g kg^{-1} seed to provide systemic protection against early-stage whitefly infestation during seedling establishment. Subsequent vector management involved sequential application of selective insecticides and botanical formu-lations at 10-day intervals before initiation of first pod setting. The spray schedule included pyriproxyfen 5% EC + fenpropa-thrin 15% EC @ 1 ml L^{-1}, spiromesifen 22.9% SC @ 1 ml L^{-1}, buprofezin 25% SC @ 2 ml L^{-1}, and neem oil @ 3 ml L^{-1}. The insecticides were selected based on different modes of action to delay resistance development in *B. tabaci* populations while ensuring effective suppression of both nymphal and adult stages. Pyripro-xyfen acted as an insect growth regulator disrupting immature development, whereas fenpropathrin provided rapid knockdown action against adult whiteflies.

Spiromesifen effectively suppressed nymphal stages by inhibiting lipid biosynthesis, while buprofezin interfered with chitin synthesis and moulting processes. Neem oil functioned as an antifeedant, oviposition deterrent, and repellent, thereby reducing dependence on synthetic insecticides and improving environmental safety.

Integrated management of vector borne virus diseases of okra

The beneficial output

The integrated module successfully maintained BYVMV disease severity (Percent disease index) below 10% up to 90 days after sowing and recorded substantially lower whitefly population density compared with farmers' conventional practices. The treatment also resulted in more than 50% enhancement in marketable fruit yield along with improved fruit quality and reduced pesticide residues, making the produce suitable for domestic consumption as well as export trade. Furthermore, the technology recorded a favourable Incremental Cost–Benefit Ratio (ICBR) of 2.50, demonstrating its economic feasibility and practical applicability under farmers' field conditions.

In addition to disease suppression and yield enhancement, the integrated module contributed significantly toward sustainable crop production through reduced insecticidal load, lower environmental pollution, minimized risk of resistance development, reduced irrigation frequency, and effective weed management. Therefore, the developed IPM technology offers a holistic, eco-friendly, and economically viable approach for sustainable management of whitefly-transmitted viral diseases in okra under eastern Indian agro-ecological conditions.

Conclusion

An integrated approach combining host plant resistance, cultural tactics to avoid peak vector populations, conservation of natural enemies and minimal insecticide use is recommended to control virus transmission and infection. Deploying resistant varieties expressing traits like increased leaf trichomes or secondary metabolites that deter *Bemisia tabaci* can limit virus spread. Optimization of planting dates, intercropping and fertilization also help suppress vectors and diseases. Conservation of biological control via natural enemies and biopesticides supplements other measures. Further research and optimization of integrated management programs are recommended since these will strengthen food security by mitigating yield losses from this damaging viral diseases.

References

Ali, M. I., Khan, M. A., Rashid, A., Ehetisham-ul-haq, M., Javed, M. T. and Sajid, M. (2012). Epidemiology of Okra Yellow Vein Mosaic Virus (OYVMV) and its management through Tracer, Mycotal and Imidacloprid. *American Journal of Plant Sciences*, 3, 1741–1745. 10.4236/ajps.2012.312212.

Givord, L. and Koenig, R. (1974). Okra mosaic virus. Commonwealth Mycolo-gical Institute/ Association of Applied Biologists. Description Plant Viruses, section 128, London.

Jamir, I., Mandal, A. K., Devi, A. P., Bhattacharjee, T., Maurya, P, K., Dutta, S., Chattopadhyay, A., Pramanik, K. and Banik, S. (2020). Screening of geno-types against viral diseases and assessm-ent of yield loss due to yellow vein mosaic virus in okra grown in the eastern part of India. *Indian Phytopathology,* 73 (2). doi.org/10.1007/s42360-019-00183-0.

Jellis, G.J. (2009) Crop plant resistance to biotic and abiotic factors: combating the pressures on production systems in a changing world. In: *Crop Plant Resistance to Biotic and Abiotic Factors* (eds. Feldmann F, Alford DV, Furk C), DPG Selbstverlag, pp.15–20.

Khatun, M. F., Hwang, H. S., Shim, J. K., Kil, E. J., Lee, S. and Lee K. Y. (2020). Identification of begomo viruses from different cryptic species of Bemisia tabaci in Bangladesh. *Microbial Pathogenesis,* 14 (8), 1040-1069. https://doi.org/10.1016/j.micpath.2020.104069

Luo, C., Jones, C. M., Devine, G., Zhang, F., Denholm, I. and Gorman, K. (2010). Insecticide resistance in *Bemisia tabaci* biotype Q (Hemiptera: Aleyrodidae) from China.*Crop Protection*, 29 (5), 429–434. 10.1016/j.cropro.2009.10.001

Sanwal, S. K., Singh, M., Singh, B. and Naik, P. S. (2014). Resistance to yellow vein mosaic virus and okra enation leaf curl virus: challenges and future strate-gies. *Current Science,* 106, 470-1471.

Seal, S. E., Jeger, M. J., Van den Bosch, F., Maramorosch, K.,Shatkin, A. J. and Thresh, J. M. (2006). Begomovirus evolution and disease management. *Advances in Virus Research,* 67, 297-316.https://doi.org/10.1016/S0065-3527(06)67008-5.

Seth, T., Chattopadhyay, A., Dutta, S., Hazra,P. and Singh, B. (2016). Evidence of Economic Heterosis and genetic control of fruit yield and yellow vein mosaic virus diseases verity traits of okra. *Vegetos*, 29 (3), 46. 10.5958/2229-4473.2016.00091.4

Shastry, K. M. S. and Singh, S. J. (1974). Effect of yellow vein mosaic virus infection on growth and yield of okra crop. *Indian Phytopathology,* 27(3), 294–297.

Singh, B., Sanwal, S., Venkataravanappa, V. and Halder, J. (2013). Breeding strategies for biotic stresses of okra: prospects and potential, In: Abstract Book of National Symposium on Abiotic and Biotic Stress Management in Vegetable Crops, Varanasi, pp.32-33.

Venkataravanappa, V., Prasanna, H. C., Reddy C. N. L. and Reddy, M. K. (2014). Evidence for two predominant viral lineages, recombination and subpopula-tion structure inbegomoviruses associated with yellow vein mosaic disease of okra in India. *Plant Pathology,* 64, 508-518. https://doi.org/10.1111/ppa.12292.

Venkataravanappa, V., Reddy, C. N. L., Jalali, S. and Reddy, M. K. (2013). Molecular characterization of a new species of bego-movirus associated with yellow vein mosaic of bhendi (Okra) in Bhubaneswar, India. *European Journal of Plant Pathology,* 136 (4), 811–822. 10.1007/s10658-013-0209-4.

Venkataravanappa, V., Reddy, C. N. L., Jalali, S. Reddy, M. K. (2015). Associ-ation of tomato leaf curl New Delhi virus DNA-B with bhendi yellow vein mosaic virus in okra showing yellow vein mosaic disease symptoms. *Acta Virologica,* 59 (2), 125-139. 10.4149/av_2015_02_125.

Wei, X., Hu, J., Yang, J, Yin, C., Du, T., Huang, M., Fu, B., Gong, P., Lian, G. J., Liu, S., Xue, H., He, C., Ji, Y., Du, H., Zhang, R., Wang, C., Li, J., Yang, X. and Zhang, Y. (2023). Cytochrome P450 CYP6DB3 was involved in thiameth-oxam and imidacloprid resistance in *Bemisia tabaci* Q (Hemiptera: Aleyro-didae). *Pesticide Biochemistry and Physiology.* 194, 105468. 10.1016/j.pestbp.2023.105468.

ISSN No. 2583-3146

Grafting: An eco-friendly Surgical Technique for Vegetable Crops

Trisha Baidya

Department of Vegetable Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal

Corresponding Author: trishabaidya01@gmail.com

Introduction

Grafting is a technique of giving birth to a new composite plant by joining two living plant parts namely, stock and scion, from two different plants. In recent days, grafting is widely used as an alternative to conventional breeding to avoid various biotic and abiotic stresses. Grafting is considered a climate-resilient strategy to maintain and increase the quality and productivity of vegetables from the harmful effects of climate change, as it possesses tolerance to salinity, drought, flooding, fluctuation of temperature, heavy metal stress and also provides resistance against several pests and diseases.

Steps of graft union formation

- Direct contact between the vascular cambium of both rootstock and scion
- Callus bridge formation
- Healing of wounds between xylem and phloem
- Formation of secondary xylem and phloem from new vascular cambium

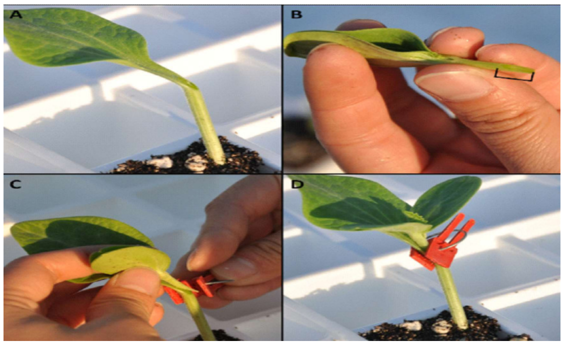
Table 1: Types of grafting and their application in vegetable crops

Type of grafting	Name of vegetable to be applied	Requirement of application
Tongue approach grafting	Cucumber and melons	Tolerance against Fusarium wilt, *Phytophthora melonisand* cold hardiness
Hole insertion grafting	Water melon	Tolerance to Fusarium wilt (*Fusarium oxysporum*), cold hardiness and drought tolerance
Splice grafting	Muskmelon	Tolerance against fusarium wilt, Phytophthora disease and cold hardiness
Cleft grafting	Brinjal	Tolerance to bacterial wilt, (*Pseudomonas solanacearum*), verticillium wilt (*Verticillium alboatrum*), low temperature and nematodes.
Micro grafting	Tomato	Tolerance against corky root (*Pyrenochaeta lycopersici*), *Fusarium oxysporum* f.sp. *radicis-lycopersici*, tolerance tonematode
Tube grafting	Capsicum	Tolerance to bacterial wilt and root knot nematode

Table 2: Suitable rootstock to overcome biotic and abiotic stress

Name of vegetable	Type of stress	Specification of stress condition	Name of rootstock
Tomato	Abiotic stress	Salt tolerance	*S. chessmanii, S. galapagense*
		Drought tolerance	*S. chilense, Solanum pennelli*
		Humidity tolerance Cold tolerance	*S. lycopersicum* var. *cerasiforme* *S. habrochaites*
	Biotic stress	Bacterial wilt resistance	Arka Alok, Arka Anmol, Arka Abhijit, Arka Shreshta
		Multiple disease resistance	*Solanum melongena, Solanum torvum*
		Fusarium wilt and nematode resistance	*Solanum nigrum, Solanum sisymbrifolium, Solanum toxicarium*
		Corky root disease resistance Tomato spotted wilt virus resistance	*Solanum habrochaites* *Solanum peruvianum*
Brinjal	Abiotic stress	Drought tolerance	*S. macrocarpon, S. gilo*
		Bacterial wilt resistance	*Solanum torvum* X *Solanum sanitwongsei, Solanum melongena* var. *Insanum, Puse Purple Cluster, Arka Nidhi, Hisar Shyamal*
		Fruit and shoot borer resistance	*S. khasianum; S. viarum*
		Furasium wilt resistance	Florida market
		Verticilium wilt resistance	*Solanum indicum*
		Tolerance to little leaf	*S. sisymbrifolium, S. auriculatum*
		Tolerance to phomopsis blight	*S. xanthocarpum*
		Rootknot nematode tolerance	*S. sisymbrifolium, S. indicum*
Cucumber	Biotic stress	Fusarium wilt resistance (*Fusarium oxysporum f cucumerinum*)	*Cucurbita ficifolia*
		Downy mildew and gummy stem blight resistance	*Cucumis hystrix*
Watermelon	Biotic stress	Fusarium wilt resistance	*Lagenaria siceraria*
Muskmelon	Biotic stress	Downy mildew and powdery mildew resistance	*Cucumis melo* var. *momordica*

Name of vegetable	Type of stress	Specification of stress condition	Name of rootstock
		Resistance against fruit fly	*Cucumis trigonus*
Bitter gourd	Biotic stress	Fusarium wilt resistance	*Luffa aegyptica*



Different types of grafting

Hole-insertion grafting

It is mainly used in rapid watermelon production where a watermelon seedling is used as a scion and a bottle gourd or squash seedling is used as rootstock.

Steps for Practising Hole-insertion grafting Technique

1. Preparation of Seedlings: Rootstock should contain one small true leaf, and the scion should have one or two true leaves.

2. Removal of thegrowing point of rootstock

- Using a pointed probe, carefully remove the true leaf along with the growing tip of the rootstock.
- Ensure the entire growing point is eliminated to prevent unwanted shoot growth.

3. Make a Slit in Rootstock Stem

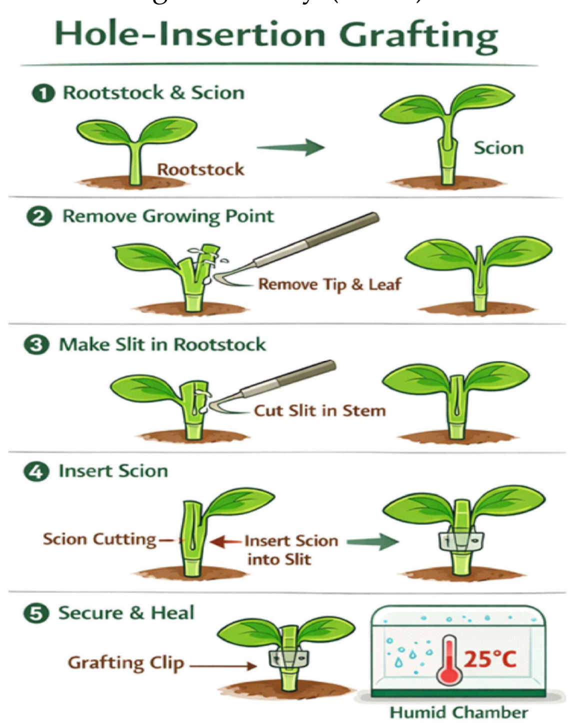
- With the probe, open a slit on the upper portion of the rootstock stem, near the cotyledons.

4. Cut and Insert Scion

- Using a sharp knife or razor blade, cut the scion.
- Insert the scion into the slit made on the rootstock stem.

5. Secure the Graft

- Hold the scion in place using a grafting clip.
- Place the grafted seedlingin a chamber with high humidity (~25°C).



Tongue Approach Grafting

Steps for Practising Tongue Approach Grafting Technique

1. Preparation of seedlings

- The seed sowing should be done 10–13 days (cucumber) or 7-10 days (pumpkin) before grafting.
- This timing ensures both scion and rootstock have similar hypocotyl diameters for proper alignment.

2. Preparation of Rootstock

- To prevent further shoot growth removal of the shoot apex of the rootstock is necessary.

3. Make Matching Cuts

- Cut the hypocotyls of both scion and rootstock so that they fit together like tongues.
- This interlocking cut helps to form a strong graft union.

4. Join and Secure

- Fit the scion and rootstock together carefully.
- The graft union is secured by using a plastic clip to hold it in place.

5. Healing of the grafted plant

- Allow the grafted plant to heal for 3–4 days while keeping the scion's root intact
- After healing, crush the scion's hypocotyl gently between fingers to weaken it.
- The hypocotyl of the scion is cut off with a sharp razor blade three or four days after crushing.

Micro-grafting

Steps for Practising Micro-grafting Technique

1. Selection of Plant Material

- Choose healthy donor plants with virus-free apical meristems.
- Collect tiny explants (< 1/1000th mm^3) from meristematic tissue.

2. Preparation of Rootstock

- The rootstock seedlings are grown under sterile in vitro conditions.
- Cut the rootstock at the appropriate stage to expose the grafting site.

3. Preparation of Scion (Meristem Explant)

- Excise the apical meristem or shoot tip carefully under a microscope.
- Trim it to the required size for grafting.

4. Grafting Procedure

- Place the meristem explant (scion) onto the prepared rootstock.
- Align vascular tissues precisely to ensure successful union.
- Secure the graft using sterile conditions to avoid contamination.

5. Culture and Healing

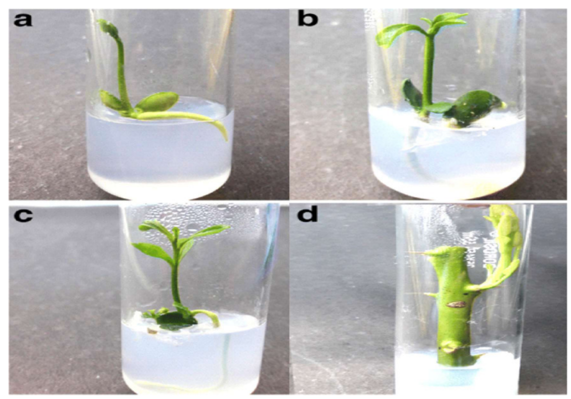
- Transfer the grafted plant to a nutrient-rich culture medium.
- Maintain controlled environmental conditions (light, temperature, humidity).
- Allow callus formation between scion and rootstock.

6. Growth and Development

- Monitor for successful graft union and shoot development.
- Gradually acclimatize the plantlets to greenhouse or field conditions.

7. Verification

- Test regenerated plants for virus elimination.
- Confirm healthy growth before large-scale propagation.



Cleft grafting

Steps for Practicing Cleft Grafting Technique

1. Seed Preparation

Rootstock seeds are sown 5–7 days before the sowing of scion seeds to ensure proper growth stages for grafting.

2. Identification of growth stage

Select scion plants atthefour-leaf stage and rootstock plants at the 4–5 leaf stage for grafting.

3. Stem Cutting

Cut both scion and rootstock stems at right angles, leaving 2–3 leaves on each stem.

4. Scion Shaping

Trim the scion stem into a wedge shape to form a tapered end suitable for insertion.

5. **Rootstock Preparation**

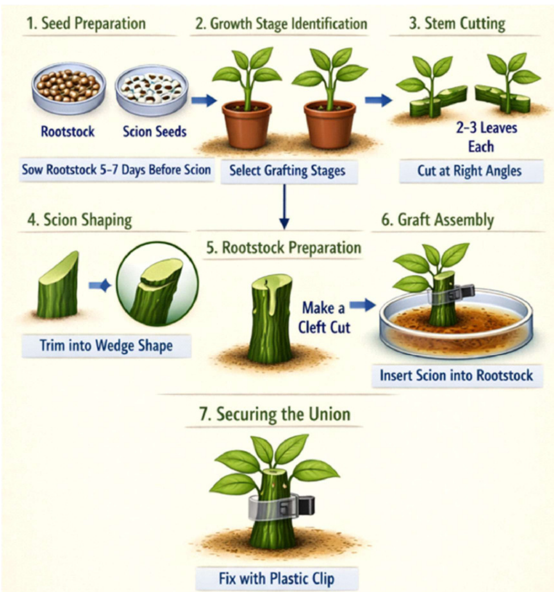
Make a cleft cut at the top of the rootstock stem to receive the scion wedge.

6. **Graft Assembly**

Insert the tapered scion end into the cleft of the rootstock, ensuring close contact between the cut surfaces.

7. **Securing the Union**

Hold the graft firmly in place using a plastic clip tomaintain alignment and stability during healing.



Splice grafting

Steps for Practising Splice Grafting Technique

Selection of the proper growth stage

Grafting is performed when both scion and rootstock plants reach the 2–3 leaf stage.

1. **Rootstock Cutting**

Cut the rootstock stem at a 30° angle, approximately 1.5 cm above the cotyledons.

2. **Scion Cutting**

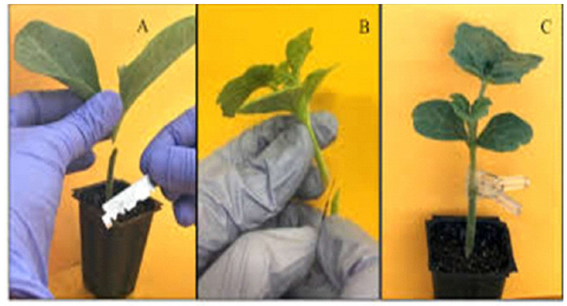
Cut the scion stem at the same 30° angle just above the cotyledons to ensure smooth and even surfaces.

3. **Graft Union Formation**

Fit the tapered scion end comfortably into the angled cut of the rootstock to align vascular tissues properly.

4. **Securing the Graft**

Hold the graft firmly using a latex tube or grafting clip to maintain contact and stability during healing.



Tube grafting

Steps for Practising Tube Grafting Technique

1. **Efficiency and Application**
   - This method allows grafting with seedlings that are grown in a small plug tray, and this technique is 2–3 times faster than conventional techniques.
   - It supports high-density planting in grafting chambers due to the smaller size of plants.
   - It is commonly practised by Japanese seedling growers for efficiency and precision.
2. **Identification of the proper growth stage for grafting**
   - The optimal grafting stage depends on the plug tray cell size.
   - Smaller cells require earlier grafting, and smaller tube diameters allow proper fit and healing.
3. **Grafting Procedure**
   - Cut both rootstock and scion stems at matching slant angles to ensure smooth contact.
   - Join the two parts using an elastic side-slit tube, which holds the scion and rootstock firmly together.
   - The tube maintains alignment and pressure, which promotes successful graft union and healing.

Current global situation of grafting

East Asia serves as the global centre for vegetable grafting. In Korea, Japan, and China, the majority of watermelon production relies on grafting, approximately 99%, 94% and 40%, respectively. Similarly, around 60–65% of tomatoes and eggplants and 10–14% of peppers are produced using grafted transplants. In the Netherlands, hydroponic tomato cultivation predominantly uses grafted seedlings, while Mexico has over 1,250 acres devoted to grafted tomato production. China also hosts more than 300 commercial grafted seedling nurseries.

Current condition of grafting in India

In India, grafting remains an emerging technology. Currently, VNR Seeds Pvt. Ltd., holds a leading position by supplying bacterial wilt-resistant grafted eggplant seedlings, produced using wild Solanum torvum as rootstock to improve yield. Other companies such as Namdhari Seeds Pvt. Ltd. (Bangalore), Jarvi Seeds Pvt. Ltd. (Gujarat) and Takii Seed India Pvt. Ltd. (Bangalore) are also adopting grafting commercially, particularly inmuskmelon, watermelon, brinjal, capsicum and tomato.

Conclusion

Commercial grafting in India is still developing, but it holds great potential for improving vegetable production under challenging conditions. Although adverse climatic conditions and attacks by disease pests prevent the productivity, India possesses rich genetic diversity in local vegetable species. These genetic resources, especially landraces, wild relatives, and underutilized species, can serve as effective rootstocks to enhance resistance to several abiotic and biotic stresses. By harnessing indigenous cucurbit, solanaceous and leguminous materials, grafting can become a sustainable tool to improve the cultivation of crops like tomato, brinjal, pepper, cucumber, muskmelon, watermelon and other vegetable crops.

References

Hassell, R. L., Memmott, F., & Liere, D. G. (2008). Grafting methods for Watermelon production.*Hort. Sci.,* 43(6), 1677-1679.

Itagi, T. (1990). Studies on the production system of the grafted nurseries in fruit vegetables(Part 1). *J. Jpn. Soc. Hortic. Sci.*, 59(1), 294-295.

Ko, K.D. 1999. Response of cucurbitaceous rootstock species to biological and environmentalstresses. Ph.D. Diss. Seoul Nat'l Univ., Korea.

Ko, K.D. 2008. Current status of vegetable seedling production in Korea and its prospects,Inauguration Seminar of Korean Plug Growers Assoc. June (2008).

Kumar, S., Saravaiya, S. N., & Patel, N. B. Training Manual on Vegetable Grafting: Concepts and Applications.

Lee, J. M., Kubota, C., Tsao, S. J., Bie, Z., Echevarria, P. H., Morra, L., & Oda, M. (2010).Current status of vegetable grafting: Diffusion, grafting techniques, automation. *Sci. Hortic.*, 127(2), 93-105.

Lee, J.M. 1994. Cultivation of grafted vegetables. 1. Current status, grafting methods, and benefits. *Hort Sci*.29, 235-239.

Lee, J.M. 2003. Advances in Vegetable Grafting. *Chron. Hort.* 43(2), 13-19.

Pandey, A. K., & Rai, M. (2003). Prospects of grafting in vegetables: an appraisal. *Veg. Sci,* 30(2),101-109.

ISSN No. 2583-3146

Spine Gourd (*Momordica dioica Roxb.*): A Promising Underexploited Vegetable Crop of India

Vinay Kumar*, Simran and Aditya Kumar Giri

Department of Vegetable Science, SAAST, Chhatrapati Shahu Ji Maharaj University, Kanpur, Uttar Pradesh

Corresponding Author: gangwarv586@gmail.com

Introduction

Momordica dioica Roxb. (spine gourd), belongs to family Cucurbitaceae with chromosome numberof 2n = 28. It is an under-utilized and under exploited vegetable crop rich in vitamins and minerals. A perennial dioicous plant, found in the forest areas of north eastern region believed to have originated in India. It is cultivated by the farmers of Assam, Tripura, Maharashtra, west Bengal, Orrisa, Chhattisgarh, Jharkhand and Bihar. This crop has great medicinal use with great potential for income generation in north east region.Spine Gourd is known as Vahisi in Sanskrit, Kantola in Hindi, Kakrol in Bengali, Batkarila in Assam and Teasel gourd in English.

Nutritional Composition in per 100 g fruit

Parameter	Nutrient Composition
Crude protein (g)	19.38
Crude lipid (g)	4.70
Carbohydrates (g)	47.92
Crude fibre (g)	21.30
Ash (g)	6.70
Calcium (mg)	33.00
Phosphorus (mg)	42.00
Iron (mg)	4.60
Calorific value (kcal)	311.50

(Source: **Tiwari *et al*., 2022**)

Vitamin Composition in per 100 g fruit

Vitamins	Vitamin Composition (g/100 g)
Vitamin A	2.5
Vitamin B1 (Thiamine)	1.8
Vitamin B2 (Riboflavin)	3.5
Vitamin B3 (Niacin)	1.9
Vitamin B5 (Pantothenic Acid)	18.0
Vitamin B6 (Pyridoxine)	4.3
Vitamin B9 (Folic Acid)	3.6
Vitamin B12 (Cyanoco-balamin)	4.0
Vitamin D2 & D3 (Cholecalciferol)	3.0
Vitamin H (Biotin)	6.5
Vitamin K (Phytonadione)	15.0

(Source: **Jha *et al*., 2017**)

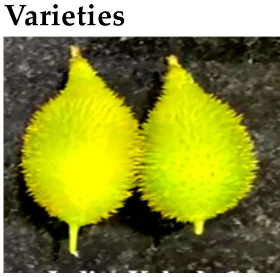
Plant parts of spine gourd contains different Phyto-constituents with influencing effects. Fruit of spine gourd is rich in hexane, methanol, n-butanol and ethyl acetate compounds which shows anti-inflammatory property, protect the liver from damage on hepatocytes, having anti-cancerous effect and have anti diabetic and antidepressant properties. There are seed oil present in seeds which provide protectant against callosobruchus chinensis and have antiallergic effect.

Different plant parts of spine gourd have different medicinal use as fruits are used to treat pimple and acne, have laxative, antipyretic, anti-asthmatic and antivenomous agent. Roots are used to reduce bowel infection and contain anti-inflammatory agent.

Climate and Soil

Spine gourd thrives well in a warm and humid climate. The optimum temperature range for its growth and development is 28-37°C. The crop performs best under moderate rainfall conditions with good sunshine. Although it can be grown in a variety of soil types, sandy loam soils rich in organic matter and having good drainage are most suitable. Waterlogged conditions should be avoided, as they adversely affect tuber development and plant growth.

Varieties



Indira Kankoda-1

Indira Kankoda-2

Chhattisgarh Kankoda-2

Arka Neelachal Shree

Arka Neelachal Shanti

Planting Material and Propagation

Spine gourd is mainly propagated through tuberous roots, which ensure uniform growth and yield. Although seed propagation is possible, it is not preferred commercially because the crop is dioecious. Seed-grown plants may produce either male or female flowers, making sex determination uncertain and reducing economic returns. To ensure proper pollination and fruit set, at least 10% male plants should be maintained in the field. The crop can also be propagated through stem cuttings, though tuber planting remains the most reliable method.

Seed Rate

Approximately 3,500-5,000 tuberous roots per hectare are required for planting one hectare of land.

Time of Sowing

Planting is generally carried out during May to July, coinciding with the onset of the monsoon. This period provides favourable temperature and moisture conditions for sprouting and vegetative growth.

Land Preparation

The selected field should be thoroughly ploughed using a tractor or power tiller to obtain a fine tilth. Proper levelling should be done to facilitate irrigation and drainage. Pits of 45 cm × 45 cm × 45 cm size should be prepared to ensure better root establishment and ease of intercultural operations.

Spacing

- Row to row distance: 1.5-2.0 m

- Plant to plant distance:80-90 cm

Proper spacing ensures adequate aeration, sunlight penetrationand ease of management practices.

Manure and Fertilization

For optimum growth and yield, apply:

- 15-20 tonnes/ha of well-decomposed Farmyard Manure (FYM) at the time of land preparation.
- Recommended NPK dose: 100:70:40 kg/ha

Nitrogen should be applied in split doses for better nutrient utilization.

Irrigation

Irrigation should be provided immediately after planting the tubers. During dry periods or when rainfall is insufficient, irrigation should be given at 5-6days interval. Irrigation is best applied during the early morning or late evening to reduce evaporation losses.

Weeding

Weeds compete for nutrients, moisture and sunlight. Therefore:

- Conduct 2-3 hand weeding at 15-20 days after planting.
- Additional weeding should be done whenever weed population becomes high.

Staking and Training

Being a climbing vine, spine gourd requires proper support. Plants should be trained on bamboo stakes and plastic wires or trellis systems. Staking improves air circulation, reduces fruit rot, enhances fruit qualityand facilitates harvesting.

Harvesting and Yield

Harvesting begins 60-70 days after planting. Fruits should be harvested at the tender greenstage, before they turn orange and develop red pulp, as this stage is ideal for vegetable consumption. Under improved production technology, the average yield ranges between 45-60 quintals per hectare.

Conclusion

Spine gourd is a nutritionally rich and medicinally valuable underutilized vegetable crop with strong potential for commercial cultivation. Adoption of improved varieties from Indira Gandhi Krishi Vishwavidyalaya and scientific production practices can enhance yield and fruit quality. With proper management and promotion, this crop can significantly contribute to nutritional security and farmers' income, especially in tropical and North Eastern regions of India.

References

Anjana, M., Swathi, V., Ramya, Sai A., Divya, N and Sunisha, Y. 2020. A Review on *Momordica dioica* Fruits. J. Adv. Plant Sci., 3: 101.

Jha, D.K., Koneri, R. and Samaddar, S. 2017. Potentia Bio-Resources of *Momordica dioica* Roxb: A Review. Int. J. Pharm. Sci. Rev. Res., 45(2): 203-209

Ponnusamy, J. and Balusamy, A. 2018. Spine gourd: An underutilized cucubitaceous vegetable. Kerala Karshakan, e-journal (December):45-47.

Talukdar, S.N. and Hossain, M.N. 2014. Phytochemical, Phytotherapeutical and Pharmacological Study of Momordica dioica. Hindawi Publishing Corporation. Evidence-Based Complementary and Alternative Medicine Volume, Article ID 806082, 11 pages.

Tiwari, J.K., Ameen, G., Sandilya, V.K., Kumar, S and Kaushik, S.K. 2022. Cultivation practices of an underutilized, yet wholesome and remunerative vegetable: Spine g o u r d . Indian Horticulture: 17-20.

Weerasinghe, M.G.W.K. and Dahanayake, N. 2021. *Momordica dioica* Roxb. (Spine Gourd)-An underutilized vegeta-ble and medicinal plant in Sri Lanka. International Journal of Minor Fruits, Medicinal and Aromatic Plants. Vol. 7 (2): 100-104

ISSN No. 2583-3146

Miyawaki

Khushboo Sharma* and Hitesh Sharma
Department of Floriculture and Landscaping, Pt. KLS CHRS, Rajnandgaon, Chhattisgarh
Corresponding Author: khushboofloriculture@gmail.com

Introduction

Miyawaki Method is one of the most effective tree planting method. It is a technique for creating dense, fast-growing, native forests on small plots of land, It involves planting 2–4 native saplings per square meter, resulting in forests that grow 10 times faster, are 30 times denser and become self-sustaining in just 2–3 years.

The Miyawaki forest method was developed by Japanese botanist Dr. Akira Miyawaki in the 1970s. This ecological technique promotes rapid, dense and sustainable native forests, growing up to 10 times faster and 30 times denser than conventional plantations by planting native species close together.

The Miyawaki Method is one of the most effective tree planting methods for creating forest cover quickly on degraded land that has been used for other purposes such as Agriculture or construction. It is effective because it is based on natural reforestation principles, i.e., using trees native to the area and replicating natural forest regeneration processes. The trees planted by this method grow much faster, jump starting the forest creation process and capturing more carbon. Higher biodiversity has been recorded in Miyawaki forests than in neighbouring woodland, so it's an ideal method for creating diverse forest ecosystems quickly. Within the context of the current climate change emergency and stark warnings about the global loss of biodiversity, being able to create diverse, healthy forests quickly could prove vital to meeting international targets and tackling these issues.

One of the most noticeable differences in a Miyawaki forest is that the seedlings are planted at very high densities. This replicates the regeneration process that occurs in a natural forest when a clearing in the canopy opens up due to a larger tree falling. The saplings grow very fast to compete for the light and then natural selection will favour the fastest growing individuals and act to thin out the trees. The result is a densely packed pioneer forest that grows in 20 to 30 years instead of taking 150 to 200 years. This has obvious benefits for projects that are working to maximize a forest's carbon sequestration potential or recreate habitat for biodiversity and wildlife.

Key Principles and Benefits

- **Native Species Only:** Uses indigenous trees adapted to local conditions to create self-sustaining ecosystems.
- **High Density:** Intense competition for light forces trees to grow upwards, rapidly creating a lush forest canopy.
- **Biodiversity:** Replicates natural forest structures with multiple layers (shrub, sub-tree, tree).
- **Urban Afforestation:** Perfect for small spaces (as small as $3m^2$) in urban areas to fight climate change and pollution.
- **Low Maintenance:** After 3 years, the

ISSN No. 2583-3146

forest requires no or minimal maintenance.

- **Environmental Impact:** These forests act as carbon sinks, reduce noise/dust, regulate surface temperature, and boost local biodiversity.

Steps to Create a Miyawaki Forest

1. **Soil Assessment:** Analyze and improve soil quality with organic materials (compost, peat).
2. **Species Selection:** Identify 15-20+ native species representing the "potential natural vegetation" of the area.
3. **Site Preparation:** Dig soil to a depth of roughly 1 meter and mix in compost.
4. **Dense Planting:** Plant seedlings randomly (not in lines) at a high density (2-4 per sq. m).
5. **Maintenance:** Mulch and water for the first 2-3 years, then allow the forest to grow naturally.

For a Miyawaki method forest, the best plants are native, fast-growing, multi-layered species suited to your local climate in Chhattisgarh. A Miyawaki plantation usually combines: Canopy trees (tall), Sub-canopy trees, Shrubs, Ground-cover species

Tall / Canopy Trees: Neem, Peepal, Banyan, Arjun, Jamun, Mahua, Sagon/Teak, Sal.

Medium Trees: Karanj, Amla, Bael, Moringa, Gulmohar.

Shrubs / Support Species: Hibiscus, Lemongrass, Karonda, Henna.

Fruit Trees (good for biodiversity): Mango, Guava, Custard Apple.

A good combination for a small backyard Miyawaki patch in Chhattisgarh could be:

- Neem + Jamun + Amla + Karanj + Hibiscus + Lemongrass.

Conclusion

The Miyawaki plantation method is an effective technique for creating dense, fast-growing, and self-sustaining forests using native plant species.Overall, the Miyawaki method is a practical and eco-friendly solution for reforestation and urban greening, promoting healthier ecosystems for future generations.

Referances

Miyawaki, A. (1999). *Creative Ecology: Restoration of Native Forests by Native Trees.* Plant Biotechnology. This is one of the foundational scientific works explaining the method and ecological principles.

Springer Nature – Akira Miyawaki Publications Contains peer-reviewed research papers on native forest restoration and ecological succession.

Food and Agriculture Organization (FAO) – Forest Restoration Guidelines Discusses ecological restoration methods, biodiversity recovery, and native afforestation.

Miyawaki, A. (1999). *Creative Ecology: Restoration of Native Forests by Native Trees*. Plant Biotechnology.

ISSN No. 2583-3146

Prospects of Home-Scale Processing of Underutilized Fruits

Ruparna Chattopadhyay[1] and Ivi Chakraborty[2]*

[1]Department of Applied Microbiology, Vellore Institute of Technology, Vellore, Tamil Nadu
[2]Department of Post Harvest Technology, BCKV, Mohanpur, Nadia, West Bengal

Corresponding Author: ivcpht@gmail.com

Introduction

Underutilized fruits are indigenous or locally available fruit species that remain largely neglected despite their considerable nutritional, medicinal, and economic importance (Williams & Haq, 2002). Important examples include bael (*Aegle marmelos*), jamun (*Syzygium cumini*), karonda (*Carissa carandas*), wood apple (*Limonia acidissima*), phalsa (*Grewia asiatica*), tamarind (*Tamarindus indica*), and aonla (*Phyllanthus emblica*). These fruits are rich in vitamins, minerals, dietary fibre, antioxidants, and various bioactive compounds while being well adapted to diverse agro-climatic conditions with relatively low production inputs (Mitra *et al.*, 2008; Singh *et al.*, 2018). Despite their abundance, commercial utilization remains limited because of poor market infrastructure, inadequate processing facilities, low consumer awareness, and high perishability (Devi & Singh, 2023).

Home-scale processing involves converting fresh fruits into stable and value-added products using simple technologies, locally available resources, and modest investments. Products such as juices, squashes, jams, jellies, pickles, candies, preserves, powders, and fermented beverages can be prepared at the household level (Barrett *et al.*, 2010). Such processing not only reduces post-harvest losses but also improves nutritional security, generates income, creates employment opportunities, and promotes sustainable utilization of indigenous fruit resources.

Reduction of post-harvest losses and enhancement of nutritional security

Many underutilized fruits are highly perishable because of their high moisture content, rapid physiological deterioration, and susceptibility to microbial spoilage (Pareek *et al.*, 2017). During peak harvest periods, large quantities of fruits become available within a short duration, often resulting in market gluts and substantial post-harvest losses. Home-scale processing offers an effective solution by converting surplus produce into shelf-stable products such as juices, squashes, candies, jams, jellies, preserves, dehydrated products and fermented beverages. These products extend fruit availability beyond the harvest season while reducing wastage and improving resource-use efficiency.

In addition to reducing losses, processing contributes significantly to nutritional security. Underutilized fruits are rich sources of vitamins, minerals, dietary fibre, polyphenols, flavonoids, anthocyanins, carotenoids, and other antioxidants (Singh *et al.*, 2018). Proper processing and storage can retain a substantial proportion of these nutrients while ensuring year-round availability. Regular consumption of processed fruit products can enhance dietary diversity, support immune function, reduce micronutrient deficiencies, and provide protection against oxidative stress-related disorders (Yahia, 2019). Thus, home-scale processing serves as an effective strategy for improving both food availability and nutritional well-being (Chakraborty *et al.,* 2011).

Income generation, employment creation and women empowerment

Value addition substantially increases the economic value of underutilized fruits by transforming them into diversified, attractive and marketable products with longer shelf life. Fresh fruits often fetch low prices during peak production periods; however, processing can significantly enhance profitability through the production of juices, syrups, squashes, jams, jellies, candies, pickles, chutneys, and dehydrated products (Rymbai *et al.,* 2016).

Home-scale processing enterprises require relatively low investment and simple equipment, making them suitable for rural households and small entrepreneurs. Such enterprises generate employment opportunities throughout the value chain, including fruit collection, sorting, grading, processing, packaging, storage, transportation, and marketing. In rural and tribal regions where employment opportunities are limited, fruit processing can provide an important source of supplementary income.

Women particularly benefit from home-scale fruit processing because these activities can be integrated with household responsibilities. The formation of self-help groups (SHGs), cooperatives and womenled enterprises facilitates collective process-ing, branding, packaging, and marketing of value-added products. Participation in such enterprises enhances household income, financial independence, entrepreneurial skills, self-confidence, and decision-making capacity, thereby contributing to gender equity and inclusive rural development (Padulosi *et al.,* 2013).

Functional foods, nutraceuticals and low-glycemic products

Growing awareness of the relationship between diet and health has increased consumer demand for functional foods and nutraceutical products. Many underutilized fruits possess exceptional nutraceutical properties and are rich in antioxidants, dietary fibre, vitamins, minerals, and bioactive compounds with recognized health benefits (Ayyanar & Subash-Babu, 2012).

The low-input nature of underutilized fruit cultivation offers substantial opportunities for developing premium-value products that cater to niche markets while simultaneously promoting sustainable agriculture, environmental conservation, and rural entrepreneurship. Jamun is valued for its anti-diabetic properties owing to anthocyanins, ellagic acid, and jamboline; aonla is renowned for its high vitamin C and antioxidant content; bael contains significant amounts of fibre and pectin; while phalsa and wood apple are rich in antioxidants and bioactive compounds (Yahia, 2019). These fruits can be processed into health beverages, ready-to-serve drinks, fruit powders, nutraceutical supplements, concentrates, and fortified foods (Singh *et al.,* 2015, 2019).

Potential value-added products

Fruits	Possible processed products
Aonla	Candy, pickle, juice, RTS beverage, powder
Bael	Squash, nectar, toffee, pulp powder
Jamun	Juice, squash, vinegar, wine, jelly, ready-to-serve beverages

Fruits	Possible processed products
Karonda	Pickle, candy, jelly, chutney
Tamarind	Concentrate, sauce, candy, beverage
Phalsa	Squash, syrup, ready-to-serve drink
Wood apple	Jam, jelly, beverage, preserve, confectionery products

Among the emerging opportunities, the development of low-glycemic index (GI) and high-fibre processed products from underutilized fruits is particularly noteworthy. Dietary fibre slows carbohydrate digestion and glucose absorption, thereby reducing glycemic response (Slavin & Lloyd, 2012). Products such as fruit powders, fruit leather, reduced-sugar jams, fibre-enriched beverages, breakfast mixes, snack bars, and bakery products fortified with fruit pulp or powder offer considerable potential for diabetic and health-conscious consumers. With increasing demand for natural, antioxidant-rich, diabetic-friendly, and minimally processed foods, underutilized fruits provide a valuable raw material base for the expanding functional food and nutraceutical sectors.

Biodiversity conservation and sustainable development

Commercial utilization of underutilized fruits through processing can contribute significantly to biodiversity conservation and sustainable resource management. Many indigenous fruit species are declining because of urbanization, habitat degradation, changing land-use patterns, and replacement by commercially dominant crops. The creation of market demand for processed products increases the economic value of these species and encourages farmers to conserve existing trees and establish new plantations.

Conservation of underutilized fruit species is particularly important because many possess unique genetic traits such as tolerance to drought, pests, diseases, and environmental stresses. These characteristics are valuable for future crop improvement programmes and for enhancing climate resilience in agricultural systems. Moreover, continued cultivation and utilization help preserve traditional knowledge, cultural heritage, and indigenous food systems associated with these fruits.

Most underutilized fruits are cultivated under low-input production systems with minimal dependence on synthetic fertilizers and pesticides. Consequently, processed products derived from these fruits can be marketed as natural, eco-friendly, and sustainable foods. Such attributes enhance their appeal among consumers seeking clean-label, environmentally responsible, and health-promoting products, creating opportunities for premium-value markets while supporting sustainable agriculture and environmental conservation.

Challenges and future outlook

Despite their considerable potential, several challenges limit the expansion of home-scale processing of underutilized fruits. These include inadequate technical knowledge, lack of processing infrastructure, poor packaging facilities, weak market linkages, limited access to finance, and low consumer awareness regarding the nutritional and medicinal benefits of these fruits. Moreover, some fruits remain underutilised due to the fact that some of these fruits are difficult to consume as fresh due to one reason or the other like, extremely small, lesser pulp/juice, large seeds, high fibre, hard coating, mucilage present, extremely sour or astringent etc. Variability in product quality, absence of standardized processing protocols, and inadequate branding further restrict market growth.

Nevertheless, future prospects remain highly promising. Advances in low-cost processing technologies, solar drying systems, improved packaging materials, and small-scale equipment have made fruit processing more accessible to rural households. The rapid growth of e-commerce, digital marketing platforms and social media-based promotion offers new opportunities for commercialization. Government initiatives supporting food processing, self-help groups, women entrepreneurship, and rural enterprises are also creating a favorable environment for value addition activities.

Furthermore, increasing consumer demand for functional foods, nutraceutical products, natural health supplements, and clean-label foods is expected to enhance market opportunities for processed underutilized fruit products. Strengthening training programmes, extension services, quality assurance systems, and market linkages will be critical for realizing the full potential of these fruits. Consequently, home-scale processing represents a sustainable pathway for improving rural livelihoods, nutritional security, biodiversity conservation, and economic development.

Conclusion

Home-scale processing of underutilized fruits represents a sustainable strategy for reducing post-harvest losses, improving nutrition, generating income and conserving biodiversity. With appropriate techn-ical support, value addition and market development, these neglected fruits can contribute significantly to rural development, food security, and livelihood enhancement while meeting the increasing consumer demand for nutritious and health-promoting foods.

References

Ayyanar, M., & Subash-Babu, P. (2012). *Syzygium cumini* (L.) Skeels: A review of its phytochemical constituents and traditional uses. *Asian Pacific Journal of Tropical Biomedicine,* 2(3), pp. 240-246.

Barrett, D.M., Somogyi, L., & Ramaswamy, H.S. (2010). *Processing Fruits: Science and Technology* (2nd ed.), CRC Press, Boca Raton, 864p.

Chakraborty, I., Chaurasiya, A.K., & Saha, J. (2011). Quality of diversified value addition from some minor fruits. *Journal of Food Science and Technology,* 48 (6), pp. 750–754.

Devi, I., & Singh, J. (2023). The potential for underutilized fruits of northern india to improve food security and their role in climate resilient- A review. *Environment and Ecology* 41(3A), pp. 1538-1545.

Mitra, S.K., Pathak, P.K. and Chakraborty, I. (2008). Underutilised tropical and subtropical fruits of Asia. *Acta Horticulturae*, 70, pp.179-82.

Padulosi, S., Thompson, J., & Rudebjer, P. (2013). *Fighting Poverty, Hunger and Malnutrition with Neglected and Underutilized Species.* Bioversity International, Rome.

Pareek, S., Yahia, E.M., Pareek, O.P., & Kaushik, R.A. (2017). Postharvest biology and value addition of tropical and subtropical fruits. In: *Postharvest Biology and Technology of Tropical and Subtropical Fruits* (Ed. Elhadi M. Yahia), Vol.1, Woodhead Publishing Limited, Oxford.

Rymbai, H., Roy, A.R., Deshmukh, N.A., Jha, A.K., Shimray, W., & War, G.F. (2016). Underutilized fruit crops and their importance in nutritional security. *Genetic Resources and Crop Evolution*, 63, pp. 125–139.

Singh A.K., Chaurasiya A. K., & Chakraborty I. (2015). Quality retention in alum treated bael (*Aegle marmelos Corr.*) preserve. *The Bioscan*, 10 (1), pp. 135-139.

Singh, A.K., Chaurasiya, A.K. and

Chakraborty, I. (2019). Quality retention of bael candy during storage. *Indian Journal of Horticulture*, 76(2), pp. 373-376.

Singh, J.P., Kaur, A., Shevkani, K., & Singh, N. (2018). Composition, bioactive compounds and antioxidant activity of common Indian fruits and vegetables. *Journal of Food Science and Technology*, 53, pp. 4056–4066.

Slavin, J.L., & Lloyd, B. (2012). Health benefits of fruits and vegetables. *Advances in Nutrition*, 3(4), pp. 506–516.

Williams, J.T., & Haq, N. (2002). *Global research on underutilised crops: An assessment of current activities and proposals for enhanced cooperation.* ICUC, Southampton, UK.

Yahia, E.M. (2019). *Postharvest Physiology and Biochemistry of Fruits and Vegetables.* Woodhead Publishing Limited, Oxford, London.

❖❖

ISSN No. 2583-3146

Advances in Canopy Architecture of Temperate Fruits

Preetika Verma[1*], Naveen Chand Sharma[2] and Mohit[3]

[1&2]Department of Fruit Science, COH, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh

[3]Department of Soil Science, COA, CSKHPKV, Palampur, Himachal Pradesh

Corresponding Author: preetika7007@gmail.com

Introduction

The canopy of a fruit tree constitutes its above-ground structural framework, encompassing the stem, branches, shoots, and leaves. The density of this canopy is determined by both the quantity and dimensions of leaves, alongside the architectural arrangement of stems and branches. Canopy architecture, in the context of fruit production, refers to the deliberate development and maintenance of tree structure in relation to its size and shape, aimed at maximizing both productivity and fruit quality (Wani et al., 2021). The fundamental premise underlying canopy management in perennial tree systems is the strategic utilization of land and climatic resources within a three-dimensional spatial framework, thereby enhancing overall orchard efficiency.

Several foundational principles govern the design and maintenance of ideal canopy architecture in temperate fruit orchards. Foremost among these is the maximization of light utilization across the entire canopy volume. Equally critical is the prevention of microclimatic conditions that favour the proliferation of pests and pathogens. Furthermore, the chosen architecture must facilitate the efficient execution of cultural operations including spraying, harvesting, and pruning, while ensuring economic feasibility in the establishment and maintenance of the desired canopy structure.

Light Interception and Canopy Architecture

Light Interception Fundamentals

Plant canopy light interception is the difference between incident solar radiation and soil-reflected radiation. Crop development depends on this characteristic, which provides energy for photosynthesis and transpiration. Plant light absorption efficiency determines carbon intake at the plant and vegetation levels, affecting biomass accumulation and growth performance.

The architecture of tree crowns affects light interception. Crown architecture greatly impacts photosynthetic activity, emphasizing the need of structural optimization in orchard management. In addition to carbon fixation, light controls flower commencement, skin coloration, flavor development, and the ratio of soluble sugars to organic acids.

Improved light interception and regular light dispersion throughout the tree canopy lead to higher fruit harvests. Fruit yield depends on light interception, but fruit quality depends on canopy light distribution. Plant density, canopy shape, and leaf area index affect light interception. As upper foliage covers lower sections, light intensity falls from the outer canopy to the interior, potentially impacting flower bud differentiation, fruit set, and color development.

Light Quality Composition and Physiological Responses

The spectral composition of sunlight undergoes substantial modification as it passes through orchard canopies, eliciting differential plant responses mediated primarily through the activity of phytochrome and cryptochrome photoreceptors High far-red to red light ratios stimulate shoot elongation, while blue light dwarfs growing shoots. Red and ultraviolet light enhance fruit skin anthocyanin synthesis, but far-red light inhibits it. These light quality responses affect vegetative growth management and fruit quality.

Several photosynthetically active wavebands affect plant physiological processes differently. The red portion of the spectrum, 620–700 nanometres, corresponds to chlorophyll's major absorption peaks and drives photosynthetic reactions most efficiently. The orange to yellow-green area from 510 to 620 nanometres captures light energy but has lesser photosynthetic activity. The most energy visible light is absorbed by chlorophyll and accessory pigments in the blue and green spectral band (380–510 nanometres). UV light below 380 nanometres is germicidal and can kill plant tissues below 260 nanometres. Carotenoids and other pigments enhance light harvesting by complementing chlorophyll absorption in this spectrum.

Training Systems for Canopy Architecture

Training involves the selective manipulation of plant parts to construct a resilient structural framework, optimize crotch angles and ensure uniform solar interception.

Traditional Training

Orchards have traditionally relied on three classical systems, each balancing specific structural and environmental needs:

- **Central Leader System:** Forms a pyramidal canopy with a dominant central trunk, commonly used for apples, pears, peaches, and plums in snowy regions.
  - o ***Pros*:** Develops strong crotch angles that resist heavy crop and snow loads.
  - o ***Cons*:** Results in unmanageable tree heights and poor light penetration in the lower canopy, reducing fruit quality.
- **Open Center System:** Creates a vase-shaped canopy by heading the main leader at 1.5 to 1.8 meters to promote 3-5 primary lateral scaffolds. It is popular for peaches, apricots, and plums.
  - o ***Pros*:** Maximizes light penetration, improving fruit color, quality, and ease of management.
  - o ***Cons*:** Prone to limb breakage from weak crotch angles, winter injury, and sunburn.
- **Modified Central Leader System:** An intermediate (delayed open center) approach where the central axis grows unpruned for 2–3 years before being headed back.
  - o ***Pros*:** Successfully balances the structural strength of a central leader with the light accessibility of an open center. It is ideal for apples, pears, walnuts, apricots, and cherries.

Modern Training Systems

Modern orchard management employs innovative training systems to maximize light interception, facilitate mechanization, and enhance early bearing potential. These approaches fundamentally rely on high-density planting, dwarfing rootstocks, and specific support structures to achieve precise canopy architectures.

Spindle Systems

- **Slender Spindle:** Developed in the early 1960s, this system utilizes a narrow, fully dwarf, conical form to achieve densities of 1,500 to 4,000 trees per hectare. Rootstocks like M.9, B.9, and G.16 are used, and the leader is trained in a zigzag pattern to restrict overall height to 2.5 to 3 metres. Upper branches bend below the horizontal under the weight of the crop load.

- **Super Spindle:** Emerging from Southern Germany in the early 1990s, this intensifies the slender spindle concept to exceed 4,000 trees per hectare. Trees are not headed at planting; instead, vigorous laterals are ripped out, and growth regulators are applied to stimulate early flower bud initiation. Height is controlled later through cuts into two-year-old generative wood.
- **Tall Spindle:** A late-1990s synthesis of the slender, vertical, and super spindle methods. It utilizes highly feathered nursery trees on fully dwarfing rootstocks planted at 1,000 to 1,500 trees per acre. Feathers are bent below the horizontal at planting, and limbs are continuously renewed rather than maintained as permanent scaffolds.

Planar and Trellis Systems

- **Vertical Axis:** Originating in France in the late 1970s, trees form a narrow pyramid up to three metres tall, accommodating 1,000 to 2,500 trees per hectare. Unlike the tall spindle, branches are maintained parallel to the ground.
- **Espalier System:** Trees are trained against a 1.5-metre trellis with three to six tiers of horizontal branches spaced approximately one foot apart. Strict lateral pruning directs growth, resulting in superior fruit quality and enhanced yields.
- **Palmette System:** Developed in Italy in the mid-1950s, this features a central leader with branches inserted at 45-degree angles, reaching heights of four to five metres. Best suited for medium-high densities, its planar architecture simplifies mechanized labor, though it requires careful vigor management to prevent intra-tree shading.
- **Tatura Trellis:** Created in Australia in 1973 to maximize yield and facilitate mechanization without necessitating dwarfing rootstocks. Trees are planted closely (6 by 1 metre) and trained across a V-shaped trellis at a 60-degree angle from the horizontal to form a continuous 0.5-metre deep fruiting canopy.
- **Cordon System:** A French technique featuring a single stem planted at a 45-degree angle, supported by three rows of wire. Shoots from lateral buds are aggressively cut back to a single leaf, optimizing sun exposure on dwarf and semi-dwarf rootstocks.

Specialized Systems

- **Joint Tree Training System:** A novel horticultural intervention patented in Japan in 2012. The apical leader of one tree is grafted directly into the bent main stem of the adjacent tree, creating a linearly joined structure. This accelerates framework establishment and flower induction while effectively resolving the vigor imbalances (excessive basal vigor and inadequate distal vigor) typical of traditional horizontal Japanese pear training systems.

Pruning Techniques and Branch Manipulation

Dormant and Summer Pruning

Pruning is essential for maintaining a tree's structural integrity and balancing vegetative and reproductive growth. The timing of pruning dictates its physiological impact:

Dormant Pruning: Conducted during the winter, this practice acts as an invigorating process. Because the tree's stored root and trunk energy reserves remain intact despite the removal of above-ground tissue, the tree responds in spring with highly vigorous shoot and bud development.

Summer Pruning: Performed four to five weeks before harvest, this devigorating practice removes photosynthetically active leaves and shoots. This limits carbon assimilation and restricts the downward flow of photosynthates, resulting in reduced root and shoot growth while simultaneously improving light penetration and reducing tree height.

Types of Pruning Cuts:

Thinning: Complete removal of a shoot to its origin; less invigorating than heading.

Heading: Removal of the terminal shoot portion to eliminate apical dominance and promote lateral buds.

Bevel/Dutch Cut: A sloping basal cut designed to encourage growth below the cut.

Click Pruning: Heading one-year-old shoots to a 5–10 cm stub to stimulate latent buds and mitigate "blind wood" in tip-bearing varieties.

Bending, Scoring, Girdling and Notching

Beyond conventional pruning, specialized physical manipulations are utilized to alter hormonal flows and enhance reproductive development.

Branch Bending: Shifting branches from vertical to horizontal orientations reduces terminal vegetative growth. This physical stress increases internal ethylene and decreases gibberellins (which typically oppose flowering), thereby promoting reproductive growth. Bending also alters auxin distribution, releasing upper buds from apical dominance. Field studies show that inclining trunks at 45 to 60 degrees can reduce shoot elongation by up to 40%.

Scoring and Girdling (Ringing): Both techniques interrupt the downward translocation of carbohydrates and hormones through the phloem. Scoring is a mild, circumscribing bark cut, while girdling involves the complete removal of a bark band. Both cause resources to accumulate above the cut, heavily favoring reproductive over vegetative growth.

Notching: A targeted phloem-interruption technique where a 2–3 mm strip of bark is removed directly above a paradormant bud. By physically blocking the downward flow of auxin from the shoot tip, notching releases the bud from suppression, successfully stimulating new lateral extension shoots in approximately 60% of treated buds.

Growth Retardants in Canopy Management

Growth retardants are synthetic chemicals that suppress cell division and elongation to create manageable tree architectures by shifting assimilate partitioning from vegetative growth to reproductive organs (Rademacher, 2000). These compounds induce distinct morphological changes, notably restricting shoot elongation, plant height, and leaf area, while maintaining or promoting root growth to increase the root-shoot ratio. Physiologically, they delay senescence, enhance chlorophyll and mineral retention, promote flowering, improve resistance to environmental stresses and increase nutrient and water efficiency. In orchard management, chemicals such as paclobutrazol, uniconazole, and chlormequat chloride effectively balance vegetative restriction with enhanced fruit quality and yield by interfering with gibberellin (GA) biosynthesis.

Based on their chemical structures and modes of action, growth retardants are classified into four main categories:

- **Onium-type compounds (e.g., chlormequat chloride):** Block GA biosynthesis prior to ent-kaurene formation.
- **Nitrogen heterocycles (e.g., paclobutrazol, uniconazole):** Inhibit monooxygenases, preventing the oxidation of ent-kaurene to ent-kaurenoic acid.

- **Acylcyclohexanediones (e.g., prohexadione-calcium):** Mimic 2-oxoglutaric acid to disrupt late-stage GA biosynthesis.
- **16,17-dihydrogibberellins:** Represent the most recently developed generation of growth retardant chemistry

Empirical Studies and Practical Applications

Extensive research confirms that optimized canopy architecture significantly enhances yield and fruit quality across temperate fruit species. In apple, the interaction between training systems and cultivars is critical. Evaluating cultivars on M.9 rootstocks, Mir *et al.*, (2020) demons-trated that the espalier system consistently outperformed vertical axis and cordon configurations by optimizing photosynth-etically active radiation (PAR). The espalier system produced the heaviest fruits (200 g), highest yields (35.70 kg/tree), and maximal light penetration (PPFD 221 μmol m^{-2} s^{-1}; LAI 0.22). Cultivar-specific responses showed Coe Red Fuji maximizing yield and total soluble solids (14.55°Brix), Granny Smith maximizing fruit size, and Spartan achieving superior color and nutritional quality due to optimal light interception.

Similarly, in 'Kiyo' Japanese plums, the joint tree training system alters hormonal balances to favor reproductive development. This structural configuration lowers bioactive gibberellins (GA_1, GA_3, GA_4) and elevates abscisic acid (ABA) in a manner analogous to shoot bending. Consequently, jointed trees exhibited a two-fold increase in flower clusters and a substantially higher fruit set (2.81%) compared to unmanipulated controls. For the 'WA38' apple, Anthony *et al.*, (2020) evaluated the interplay of training systems, rootstocks, and pruning techniques. While V-shaped canopies and Geneva 41 rootstocks maximized overall light interception, combining spindle training with Nic29 rootstocks and "click" pruning proved highly effective for yield stability. This specific management sequence maintained optimal light interception and leaf area indices while effectively mitigating alternate bearing and blind wood development.

Chemical canopy management using paclobutrazol (PBZ) offers dose-dependent regulation of tree vigor. In 'Fuji' apples, moderate PBZ applications (1,000–1,500 mg/L) during fruit enlargement decreased indole-3-acetic acid and gibberellic acid while increasing ABA. This application restricted vegetative growth and optimized carbon-nitrogen partitioning-reducing nitrogen accumulation in fruits while increasing fruit carbon and root carbohydrate reserves-thereby enhancing overall fruit quality and postharvest storage potential. Two sequential foliar sprays of prohexadione-calcium (125–150 ppm), applied initially at the 3–5 leaf stage and again 25 days later, effectively balance vegetative and reproductive growth in rejuvenated apple trees. Specifically, the 150 ppm treatment significantly restricts vegetative growth while maximizing fruit set (82.38%), surface red coloration (80.60%), yield (33.96 kg/tree), and return bloom.

Conclusion

The structure of fruit tree canopies is a key factor influencing orchard productivity, fruit quality and operational efficiency. Effective light interception and even distribution of photosynthetically active radiation within the canopy are essential for maximizing yields and ensuring high fruit quality. The reviewed evidence shows that canopy architecture requires careful attention through the integration of suitable scion and rootstock combinations, the selection of appropriate training and pruning systems based on species and cultivar traits, and the strategic use of growth-regulating compounds. With growing demands for better resource efficiency and environmental sustainability in horticulture, optimizing canopy architecture through integrated management will be crucial for advancing orchard systems.

References

Anthony, B., Serra, S., & Musacchi, S. (2020). Optimization of light interception, leaf area and yield in "WA38": Comparisons among training systems, rootstocks and pruning techniques. Agronomy, 10(5), 689.

Greene, D. W., & Lord, W. J. (1983). Effects of dormant pruning, summer pruning, scoring and growth regulators on growth, yield and fruit quality of "Delicious" and "Cortland" apple trees. Journal of the American Society for Horticultural Science, 108, 590-595.

Mir, J. I., Ahmed, N., Singh, D. B., Sharma, O. C., Raja, W. H., Shafi, W., Zaffer, S., Jan, S., &Kirmani, S. N. (2020). Canopy management to improve fruit quality of Coe Red Fuji, Granny Smith and Spartan varieties of apple (Malusdomestica). Indian Journal of Agricultural Sciences, 90(8), 1397-1401.

Rademacher, W. (2000). Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annual Review of Plant Biology, 51(1), 501-531.

Wani, R. A., Din, S., Khan, M., Hakeem, S. A., Jahan, N., Lone, R. A., Baba, J. A., Parray, G. N., & Khan, J. A. (2021). Canopy management in fruit crops for maximizing productivity. International Journal of Chemical Studies, 9(3), 160-165.

ISSN No. 2583-3146

The Silent Spreaders: Emerging Trends in Insect-Vector Plant Disease Transmission

Anubhav Galav*, Valenta Kangjam and Arvind Swami
Department of Vegetable Science, Mewar University, Chittorgarh, Rajasthan
Corresponding Author: anubhavglv@gmail.com

Introduction

Plant diseases, caused by viruses, bacteria, fungi, and phytoplasmas, are a major limiting factor in agricultural productivity worldwide. While some pathogens are directly transmitted through seed, soil, or mechanical means, a significant and increasingly problematic proportion relies on biological vectors for their dissemination. Among these vectors, insects, particularly those belonging to the orders Hemiptera (aphids, whiteflies, leafhoppers, plant hoppers, psyllids) and Thysanoptera (thrips), are by far the most important, facilitating the spread of numerous devastating plant diseases [1, 2]. The efficiency of insect-mediated transmission lies in their mobility, feeding habits, and often specific biological relationships with the pathogens they carry.

In recent decades, the landscape of insect-vectored plant diseases has undergone significant shifts, driven by a confluence of factors including globalization, changes in agricultural practices, and perhaps most profoundly, climate change [3]. This review aims to explore these emerging trends, providing a comprehensive overview of the current understanding of insect-vector plant disease transmission and the challenges and opportunities for future research and management.

Emerging Trends in Vector-Borne Plant Diseases

The increased frequency and severity of insect-vectored plant disease epidemics can be attributed to several interconnected emerging trends:

Diversification and Expansion of Vector Species

Historically, certain insect groups have been well-known vectors. However, we are now observing a diversification of vector species and an expansion of their geographical ranges. For instance, new biotypes or invasive populations of established vectors, such as the whitefly *Bemisia tabaci*, are constantly emerging, exhibiting enhanced vector competence and broader host ranges [4]. Similarly, species previously considered minor vectors are gaining prominence as environmental conditions shift, favoring their populations and their ability to acquire and transmit pathogens [5]. This expansion is often facilitated by international trade of plant materials, inadvertently introducing new vectors and pathogens into vulnerable agricultural ecosystems [3].

Evolution of Pathogen Virulence and Host Adaptation

Plant pathogens, particularly viruses and phytoplasmas, are highly adaptable and undergo rapid evolution through mutation, recombination, and selection pressure. This leads to the emergence of novel strains with increased virulence, broader host ranges, or enhanced ability to be acquired and transmitted by their insect vectors [6]. For example, new recombinant strains of Potato virus Y (PVY) have emerged, posing significant threats to tobacco, tomato, and pepper crops [7]. Similarly, highly virulent strains of Tomato yellow leaf curl virus (TYLCV), transmitted by whiteflies *(Bemisia tabaci)*, have spread worldwide and caused severe yield losses in tomato-growing regions. Rice tungro disease, caused by Rice tungro bacilliform virus (RTBV) and Rice tungro spherical virus (RTSV) and transmitted by green leafhoppers, continues to evolve, leading to periodic outbreaks in Asian rice ecosystems. Likewise, Cassava mosaic begomoviruses, transmitted by whiteflies, have evolved through recombination events, resulting in devastating epidemics in cassava-producing areas.

Among phytoplasma diseases, Sugarcane grassy shoot disease, transmitted by leafhoppers, and Brinjal little leaf disease, spread by jassids (*Hishimonus phycitis*), are notable examples where pathogen adaptation has enhanced disease spread and severity. Sesame phyllody phytoplasma and Sandal spike disease phytoplasma also demonstrate the capacity of phytoplasmas to evolve and establish efficient relationships with both plant hosts and insect vectors.

The co-evolutionary arms race between plants, pathogens, and vectors often results in pathogens manipulating host plant physiology or insect behaviour to their advantage, thereby optimizing their transmission success [8]. For instance, virus-infected plants may produce altered volatile compounds that attract insect vectors, increasing pathogen dissemination. Such evolutionary adaptations present significant challenges for disease management and necessitate continuous monitoring of pathogen populations and vector dynamics.

Climate Change as a Catalyst

Climate change is arguably the most significant driver of emerging trends in insect-vectored plant diseases. Rising global temperatures directly impact insect biology, including their development rates, reproduction, dispersal and overwintering survival [9]. Warmer temperatures can lead to:

- **Increased Vector Generations:** Shorter insect life cycles mean more generations per growing season, leading to rapidly escalating vector populations.
- **Expanded Geographic Ranges:** Formerly unsuitable cold regions become hospitable, allowing vectors and their associated pathogens to colonize new areas [3].
- **Altered Vector-Pathogen Interactions:** Temperature influences the extrinsic incubation period (EIP) of pathogens within their insect vectors, often shortening it and accelerating disease spread [9].
- **Changes in Plant Physiology:** Climate stress can weaken plant defenses, making them more susceptible to infection and more attractive to vectors.
- **Extreme Weather Events:** Altered precipitation patterns and extreme weather events can disrupt natural predatorprey dynamics, further favouring vector outbreaks.

These climate-induced changes contribute significantly to the increased incidence and severity of vector-borne epidemics globally [3].

Mechanisms of Transmission and Molecular Insights

Understanding the intricate molecular interactions at the plant-insect-pathogen interface is critical for developing effective control strategies. Insect vectors transmit pathogens through various mechanisms, broadly classified as non-persistent, semi-persistent, and persistent (circulative or propagative) [1].

- **Non-persistent transmission:** The pathogen is acquired and transmitted rapidly during brief feeding probes and is retained only on the insect's stylets. The insect loses its ability to transmit the pathogen within minutes to hours. Example: *Cucumber mosaic virus* transmitted by aphids such as Myzus persicae and Potato virus Y transmitted by several aphid species.
- **Semi-persistent transmission:** The pathogen is retained in the insect's foregut and can be transmitted for several hours to a few days, but it does not circulate within the insect body or replicate in the vector. Example: *Citrus tristeza virus* transmitted by aphids and Beet yellows virus transmitted by aphid vectors.
- **Persistent transmission:** The pathogen passes through the insect gut into the haemolymph and salivary glands, allowing transmission for the insect's lifetime. In persistent circulative non-propagative transmission, the pathogen circulates within the insect but does not replicate. Examples: *Tomato yellow leaf curl virus* transmitted by the whitefly Bemisia tabaci and Barley yellow dwarf virus transmitted by aphids. In persistent propagative transmission, the pathogen both circulates and multiplies within the insect vector. Examples: Rice tungro disease transmitted by green leafhoppers and phytoplasmas causing Sugarcane grassy shoot disease and Brinjal little leaf disease transmitted by leafhoppers and jassids.

Recent advances in molecular biology and genomics are shedding light on the precise molecular interactions underpinning these transmission modes. Researchers are identifying specific proteins in both the pathogen and the insect that mediate acquisition, retention, and inoculation [10]. For example, studies are revealing how plant pathogens can manipulate plant volatile organic compounds (VOCs) to attract insect vectors, thereby increasing their chances of acquisition and transmission [8]. Furthermore, understanding the molecular determinants of vector competence (the ability of an insect to acquire and transmit a pathogen) is paving the way for novel interventions, such as gene editing approaches to interfere with pathogen uptake or replication within the vector [11].

Management Strategies and Future Directions

Traditional methods of managing insect-vectored plant diseases have primarily relied on chemical insecticides to control vector populations. However, the emergence of insecticide resistance, environmental concerns and the desire for sustainable agriculture necessitate a shift towards integrated pest management (IPM) strategies. Emerging trends in management include:

Resistant Varieties and Genetic Engineering

Developing and deploying plant varieties with genetic resistance to either the insect vector or the pathogen remains a cornerstone of sustainable disease management. Advances in genetic engineering and genome editing (e.g., CRISPR/Cas) offer promising avenues to introduce or enhance resistance genes in crops, either by targeting host factors crucial for pathogen infection or by interfering with vector feeding or transmission [11].

Several resistant varieties and genetically engineered crops have been developed in recent years to combat devastating viral diseases. For example, tomato cultivars carrying the Ty-1, Ty-2, Ty-3, and Ty-6 resistance genes provide effective resistance against Tomato yellow leaf curl virus (TYLCV), a whitefly-transmitted begomovirus. In cassava, varieties resistant to Cassava mosaic disease (CMD) and Cassava brown streak disease (CBSD) have been released in several African countries, significantly improving productivity. Similarly, rice breeding programs have developed varieties possessing resistance genes against Rice tungro disease, reducing losses caused by tungro viruses transmitted by green leafhoppers.

Genetic engineering has also contributed to the development of virus-resistant crops. The transgenic Rainbow papaya, engineered with the coat protein gene of Papaya ringspot virus (PRSV), has provided durable resistance and successfully revived papaya production in affected regions. More recently, CRISPR/Cas-mediated genome editing has been employed to modify host susceptibility genes such as eIF4E, conferring resistance against several potyviruses in tomato, cucumber, and other crops. Researchers have also utilized CRISPR/Cas systems to directly target viral genomes of begomoviruses, including Tomato yellow leaf curl virus and Cotton leaf curl virus, demonstrating promising resistance under experimental and field conditions. These advances highlight the growing potential of modern biotechnology to develop durable and broad-spectrum resistance against insect-transmitted plant viruses.

This integrated approach combining conventional breeding, marker-assisted selection, transgenic technologies, and genome editing is expected to play a pivotal role in future disease management strategies.

Biological Control

Utilizing natural enemies of insect vectors, such as parasitoids, predators and entomopathogenic fungi, is an increasingly important component of IPM. Conservation and augmentation of these beneficial insects can significantly reduce vector populations and, consequently, disease incidence [12].

Precision Agriculture and Surveillance

Technological advancements, including remote sensing, drone technology, and artificial intelligence (AI) with deep learning algorithms, are revolutionizing disease surveillance and early detection [13]. This allows for timely and targeted interventions, reducing the reliance on broad-spectrum treatments and minimizing environmental impact.

Understanding "One Health" in Plant Pathology

The concept of "One Health," which recognizes the interconnectedness of human, animal and environmental health, is increasingly relevant to plant disease management. Factors affecting vector populations and pathogen dynamics in one ecosystem can have ripple effects on others. This holistic approach emphasizes interdisciplinary collaboration for effective disease control.

Conclusion

The emerging trends in insect-vectored plant disease transmission present formidable challenges to global agriculture. The dynamic interplay between evolving vector populations, adaptable pathogens, and a changing climate creates a complex landscape for disease management. However, significant progress in understanding the ecological, epidemiological and molecular aspects of these interactions is paving the way for innovative and sustainable solutions. A multi-pronged approach integrating host resistance, biological control, advanced surveillance technologies, and a deeper understanding of vector-pathogen molecular mechanisms will be crucial in mitigating the impact of these silent, yet potent, spreaders on global food security. Continued research, international collaboration, and proactive policy development are essential to stay ahead of these evolving threats.

ISSN No. 2583-3146

References

Jayasinghe, W. H., Akhter, M. S., Nakahara, K., & Maruthi, M. N. (2022). Effect of aphid biology and morphology on plant virus transmission. *Pest Management Science*, 78(2), 416-427.

A Comprehensive Review on Plant Disease Vectors and Their Management. (2023). *International Journal of Environment and Climate Change*, 13(9), 2518-30.

Impact of Climate Change on Insect Vectors and Vector-Borne Plant Viruses and Phytoplasma. (2015). *ResearchGate*.

Fuchs, M. (2020). Believing is seeing: Lessons from emerging viruses in grapevine. *Journal of Plant Pathology*, 102, 619-632.

Review Article: Plant Viruses Transmitted by Insects. (2024). *European Journal of Theoretical and Applied Sciences*, 6(1), 1217.

Genome editing: A novel approach to manage insect vectors of plant viruses. (2024). *Insect Biochemistry and Molecular Biology*, 174, 104189.

Recent advances and challenges in plant viral diagnostics. (2024). *Frontiers in Plant Science*, 15, 1451790.

Beetles as Plant Pathogen Vectors. (2021). *Frontiers in Plant Science*, 12, 748093.

The Impact of Climate Change on Agricultural Insect Pests. (2022). *MDPI Insects*, 12(5), 440.

Pathogen Binding and Entry: Molecular Interactions with the Insect Gut. (2025). *Annual Review of Entomology*. (Ahead of Print).

Genome editing: A novel approach to manage insect vectors of plant viruses. (2024). *Insect Biochemistry and Molecular Biology*, 174, 104189.

Integrated Management of Insect Vectors of Plant Pathogens. *ARCC Journals Agricultural Reviews*.

Advances in Deep Learning Applications for Plant Disease and Pest Detection: A Review. (2024). *MDPI Remote Sensing*, 17(4), 698.

❖❖

ISSN No. 2583-3146

Bakwa Bottle: The Future of Eco-Friendly Packaging

Garima Kaushik Parashar* and Mahima Rana
Department of Agriculture, GRD Institute of Management & Technology, Dehradun
Corresponding Author: garimakaushik1991@gmail.com

Introduction

Plastic pollution has become one of the biggest environmental problems in the modern world. Every year, millions of plastic bottles are thrown into rivers, oceans, and landfills, where they remain for hundreds of years. To solve this problem, eco-friendly alternatives are being developed across the world. One such innovation from India is the Bakwa Bottle - a biodegradable bottle made from plant-based materials. The Bakwa Bottle represents a combination of science, sustainability, and social responsibility. It shows how chemistry and biology can work together to create solutions for environmental problems.

The Story Behind Bakwa

The idea of Bakwa Bottle was developed by three young friends from Kerala-Aswin, Alen and Basil. They were disturbed by the increasing amount of plastic waste polluting Kerala's famous backwaters and beaches. Instead of simply discussing the issue, they decided to create apractical solution. Their goal was to design a bottle that would perform like plastic but would not remain in the environment for centuries. After research and experimentation, they introduced Bakwa, a bottle made from biodegradable bioplastic. Their innovation soon gained attention as an environmentally friendly alternative to traditional plastic bottles.

Bakwa Bottle

A Bakwa Bottle is a biodegradable water bottle made from renewable plant sources such as:

- Sugarcane
- Corn starch
- Plantsugars

The bottle is manufactured using a bioplastic called PLA (Polylactic Acid). Unlike petroleum-based plastic, PLA is derived from natural materials and can decompose naturally under composting conditions.The bottle looks and functions like an ordinary plastic bottle but is far less harmful to the environment.

Chemistry Behind Bakwa Bottle

PLA

PLA stands for Polylactic Acid, a biodegradable polymer made from lactic acid. It is one of the most widely used bioplastics in the world.

Formation Process

1. Plant starch is converted into glucose
2. Glucose undergoes fermentation
3. Fermentation produces lactic acid
4. Lactic acid molecules join together through polymerization
5. The final product formed is PLA

$$nC_3H_6O_3 \rightarrow (C_3H_4O_2)_{n+n}H_2O$$

$$C\ _3H_6O_3 \rightarrow C_3H_4O_2$$

$$H_2O_nC_3H_6O_3 \rightarrow (C_3H_4O_2)n+nH_2O$$

ISSN No. 2583-3146

This process is an example of condensation polymerization.

Chemical Properties

- Non-toxic
- BPA-free
- Lightweight
- Heat resistant
- Biodegradable

Unlike traditional plastics, PLA does not release harmful chemicals into water or soil.

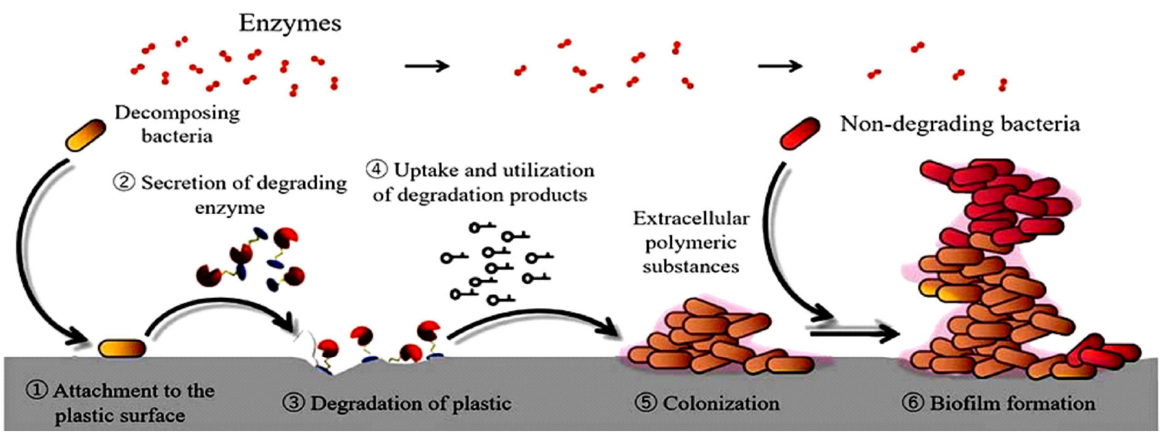
Biological Importance of Bakwa Bottle

The Problem of Microplastics

Normal plastic bottles slowly break into tiny particles called microplastics. These particles enter:

- Drinking water
- Marine ecosystems
- Food chains
- Human bodies

Microplastics can affect both animals and humans and may lead to serious health and environmental issues. Bakwa Bottles decompose naturally through the action of bacteria, fungus and enzymes. These microorganisms break down the bottle into carbon dioxide, water and biomass. As a result, the bottle leaves little or no toxic residue behind.



Advantages of Bakwa Bottle

1. Environment Friendly: The bottle reduces plastic waste and pollution.

2. Made from Renewable Resources: It uses plant-based materials instead of petroleum.

3. Biodegradable: It decomposes within months under suitable conditions.

4. Safe for Human Use: It is BPA-free and non-toxic.

5. Supports Sustainable Development: It promotes eco-friendly industrial practices.

Limitations of Bakwa Bottle

Despite its advantages, Bakwa Bottle also faces certain challenges:

- More expensive than regular plastic bottles
- Requires industrial composting for faster decomposition
- Limited availability in the market
- Production on a large scale is still developing

These limitations show that while biodegradable bottles are promising, further technological improvements are needed.

Conclusion

The Bakwa Bottle is an excellent example of how innovation can help protect the environment. Developed by young entrepreneurs from Kerala, it combines chemistry, biology, and sustainability to create a practical solution to plastic pollution.

Although biodegradable bottles still face economic and industrial challenges, they represent an important step toward a cleaner and greener future. If more industries and consumers adopt such eco-friendly alternatives, the harmful impact of plastic pollution can be greatly reduced.In a world struggling with environmental damage, the Bakwa Bottle reminds us that even a simple water bottle can become a powerful tool for change.

ISSN No. 2583-3146

Digital Horticultural Extension: Empowering Farmers Through Smart Technologies, Innovation and Market Linkages

Vaibhav Singh and Uddeshy Singh*

[1]Department of Agricultural Extension and Communication and [2]Department of Horticulture

SHUATS, Prayagraj, Uttar Pradesh

Corresponding Author: uddeshysingh61238@gmail.com

Introduction

Horticulture, encompassing fruits, vegetables, and plantation crops, represents a vital sector for enhancing farmer incomes and ensuring nutritional security. However, horticultural farmers, particularly smallholders, face persistent challenges: climate variability, pest outbreaks, post-harvest losses, and volatile markets. Traditional extension systems, constrained by limited resources and reach, often struggle to provide timely, location-specific advice to millions of scattered farmers. The digital revolution in agriculture is fundamentally transforming this landscape. Digital Horticultural Extension leverages Information and Communication Technologies (ICT) to deliver personalized, data-driven advisory services, enabling farmers to make informed decisions that optimize resources, improve productivity, and enhance market access. By integrating tools like mobile applications, artificial intelligence (AI), drones, and community radio, digital extension is bridging critical information gaps and empowering farmers with knowledge that was previously inaccessible.

Methods

The digital transformation of horticultural extension is built on a multi-layered architecture combining diverse technologies, delivery channels, and institutional mechanisms to effectively reach and empower farmers.

1. Digital Advisory Platforms: Mobile applications form the backbone of digital extension. Platforms like Pusa mKRISHI deliver personalized, real-time advisories on weather-based crop care, pest management, and soil health. Bihar Agricultural University distributes agro-met advisory bulletins via the m-Kisan Portal and WhatsApp, benefiting millions of farmers. More advanced AI-powered platforms, such as Digital Green's Farmer Chat, offer multimodal, multilingual support, diagnosing pests from uploaded photos and providing tailored crop management advice.

2. Innovative, Low-Cost Technologies: Initiatives like QR-code-based extension at KVK Akola demonstrate how simple digital tools can be highly effective. Farmers scan QR codes displayed at input shops and training centres, gaining instant, paperless access to over 164 topics across six thematic domains, including horticulture.

3. Precision Agriculture and Remote Sensing: Drones and IoT sensors enable precision resource application. Drone-based

ISSN No. 2583-3146

spraying demonstrations have shown significant pest reduction, outperforming traditional methods.

4. Community Media and Social Platforms: WhatsApp and community radio are vital for localized dissemination. While WhatsApp enables efficient video sharing among farmers, studies highlight the importance of using it as a complement to, not a replacement for, face-to-face interactions. Community radio has shown higher knowledge retention among listeners.

5. Market Linkage Platforms: Digital platforms like the North Eastern Region Agri-Commodity E-Connect (NE-RACE) portal directly connect farmers (FPOs, SHGs) with buyers, minimizing middlemen and enabling fair price discovery. India's first digital apple market by Adani Agri-Fresh uses transparent online auctions, uniform grading, and direct payments.

Results

Empirical evidence demonstrates that digital horticultural extension has yielded significant positive outcomes across multiple dimensions.

1. Enhanced Knowledge and Adoption: Digital platforms substantially improve farmer knowledge. A study using a Difference-in-Difference (DID) approach found that users of the Kisan Sarathi advisory system showed a highly significant increase ($\beta=4.36$, $p<0.001$) in knowledge scores compared to non-users. Similarly, exposure to QR-code-based content resulted in a statistically highly significant knowledge gain ($t=18.62$, $p<0.01$), with adoption of recommended practices ranging from moderate to high. Participatory video learning through Digital Green has improved adoption of agricultural practices in Madhya Pradesh.

2. Economic Empowerment: Digital platforms are translating knowledge into tangible economic benefits. Comparative studies show that digital platform users have significantly higher adoption indices, yield, and net farm income than non-users. The AI-enabled Farmer Chat initiative targets a 20% household income increase for 30% of active users over three years. At Adani's digital apple market, farmers reported transparent pricing, reduced rejections, and online payments, with apples selling for Rs 2200 per crate. The NE-RACE portal aims to ensure fair compensation through direct negotiation with buyers.

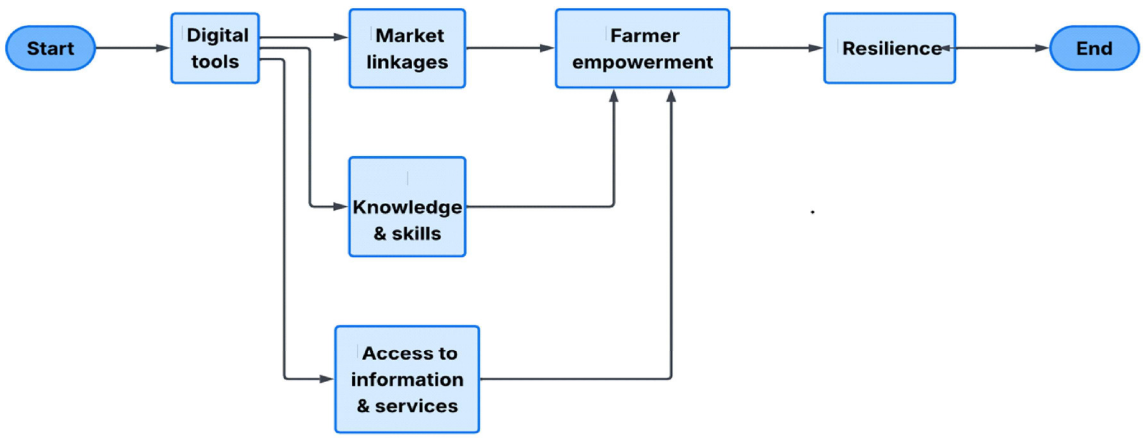
3. Improved Resilience and Sustainability: Digital advisory services promote climate-resilient practices. A Randomized Control Trial found that farmers with access to Digital Advisory Services were significantly more likely to adopt Sustainable Land Management Practices like green manuring and intercropping. Agent-based and hybrid delivery models showed the highest adoption rates, especially among women farmers.

Table 1: Impact of Digital Horticultural Extension Interventions

Intervention / Platform	Target Beneficiaries	Key Outcome(s)	Evidence/ Statistic
Kisan Sarathi Advisory	Farmers in Uttar Pradesh	Significant increase in knowledge	Î²=4.36, p<0.001 (DID model)
QR Code-Based Extension	Farmers in Akola, Maharashtra	High knowledge gain & moderate-high adoption	t=18.62, p<0.01; DEEI high for >51% users

Intervention / Platform	Target Beneficiaries	Key Outcome(s)	Evidence/ Statistic
Drone-Based Spraying	Horticultural farmers in Gurugram	Pest reduction in horticultural crops	80-84% pest reduct-ion (vs. traditional methods)
AI-Enabled Farmer Chat	50,000 farmers across 8 Andhra districts	Targeted income increase & practice adoption	Target:2 0% income increase for 30% active users
Digital Apple Market	Apple growers in Himachal Pradesh	Price transparency, direct payment, farmer control	Direct online auctions, Rs 2200/crate reported

Figure 1: Conceptual Model of Digital Horticultural Extension Impact Pathway



Impact pathway showing how digital tools improve access, knowledge, and market linkages, leading to enhanced farmer empowerment and resilience.

Conclusions

Digital horticultural extension is emerging as a powerful catalyst for transforming smallholder farming. The evidence demonstrates that it successfully delivers personalized, timely, and actionable information, leading to significant increases in farmer knowledge, adoption of improved practices and economic empowerment. Initiatives like drone-based pest control, QR-code advisories, AI-powered chatbots, and digital market platforms are not just incremental improvements but represent a paradigm shift in extension service delivery. They enable farmers to move from a reliance on generalized, often outdated advice to data-driven, precision agriculture.

However, the transition from advisory to true empowerment requires addressing persistent challenges. The digital divide -in terms of access, literacy, and affordability remains a critical barrier, particularly for women and marginalized groups. Studies on WhatsApp usage highlight that while digital tools are efficient for information dissemination, they must not replace face-to-face extension, as they can limit two-way discussion, feedback and social inclusivity. Successful digital extension models emphasize a hybrid approach that combines technology with human facilitation.

The future of digital horticultural extension lies in creating inclusive, integrated, and scalable digital ecosystems. This involves strengthening rural digital infrastructure, investing in digital literacy, developing local-language content, and ensuring seamless integration between advisory services and market linkages. Platforms like NE-RACE and Farmer Chat exemplify this integration, providing a one-stop solution for production advice and market access. Government policies should focus on fostering public-private partnerships, supporting innovations like AI and IoT in agriculture, and promoting agent-based models that ensure equitable access. When implemented thoughtfully, digital horticultural extension can bridge information gaps, empower farmers with knowledge and market power, and pave the way for a sustainable and profitable horticulture sector.

References

Coggins, S., Munshi, S., Smith, J., Yadav, A. K., Poonia, S. P., Patil, S., Singh, N. K., Sawarn, A., Ireland, D. C., McDonald, A. J., Singh, D. K., Sherpa, S. R., &Craufurd, P. (2025). How do chat apps support the use of farming videos in agricultural extension: A case study from Bihar, India. NJAS: Impact in Agricultural and Life Sciences, 97(1), 2420803.

Deccan Herald. (2026, January 8). Andhra horticulture farmers to get AI climate smart advisories via Mobile App.

ET Edge Insights. (2026, January 7). Digital Green and Cisco CSR launch AI-powered advisory for farmers in Andhra Pradesh.

Maurya, A. S., Yadav, B., Patel, S., Kumar, R., & Kumar, A. (2026). Assessing the Role of Digital Platforms in Strengthening Agricultural Extension Services: Advisory to Empowerment. Indian Journal of Extension Education.

Mishra, S., Suresh, R. H., & Bhatt, J. P. (2025). Enhancing climate-resilient farming through digital advisory services: Evidence from an RCT on SLMP adoption. Tropentag 2025.

Padaria, R. N., Mukherjee, S., Ghosh, B., Shravani, K., Sarkar, S., Sharma, A., Singh, B., & Papnai, G. (2025). ICT-enabled technology delivery for sustainable horticulture. Indian Horticulture, 69(6).

Press Information Bureau. (2024, August 7). North Eastern Region Agri-Commodity E-Connect Web Portal. Ministry of Development of North Eastern Region.

Singh, D. R., & Panda, C. K. (2025). Digital initiatives in horticulture for eastern India. Indian Horticulture, 69(6).

Thakare, U. G. (2026). QR Code–based Digital Extension for Next-generation Agri-extension. Journal of Experimental Agriculture International, 48(5), 207-215.

Thakare, U. G., & Mahalle, S. B. (2026). Paperless Agricultural Extension through QR Codes: A Conceptual Framework and Empirical Evaluation of the KVK Akola Initiative. Journal of Experimental Agriculture International, 48(5), 216-226.

❖❖