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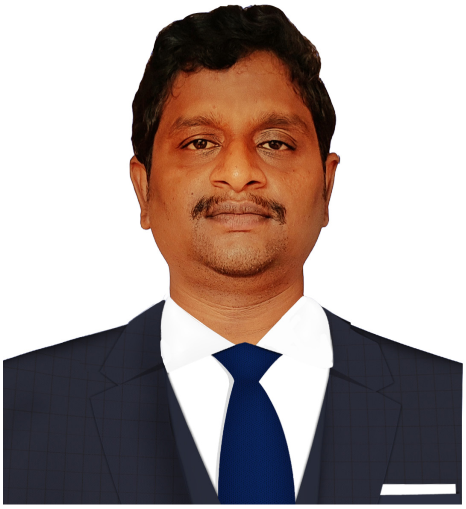
## From the Desk of Editor-in-Chief



With immense humbleness and anticipation, I seek it's my pleasure to launch the April 2026 issue of the **"Krishi Netra"** a monthly e-Magazine subtitled "Invisible Vision on Farming" published by **GRN Creatives**. On behalf of the Krishi Netra Editorial Team, I would like to take this opportunity to thank our authors, editors, reviewers and all of them who have volunteered to contribute to the successful release of the first (December) issue of the e-Magazine.

The magazine aims to provide a common platform for the scientific community, research scholars and other readers to publish their ideas, new inventions, research findings etc., to provide the invisible insights for betterment of the farming community. Krishi Netra magazine is primarily focused on the areas of Agriculture, Horticulture, Precision Farming, Fisheries & Animal Sciences, Agriculture Engineering, Agribusiness Management, Food & Dairy Technology, Bio-Sciences/ Life-Sciences, Biotechnology & Biochemistry, Environmental Science &Forestry, Organic Farming, Sericulture and Home Science.

As we turn the pages of Krishi Netra, let us celebrate the unsung heroes, the farmers, the agri-entrepreneurs, the scientists, and the agri scholars. Together, we delve into the realms of sustainable practices, agro ecology, and the transformative power of technology, ensuring that the seeds we sow today yield a bountiful harvest for generations to come.

May this magazine be a source of inspiration, knowledge, and appreciation for the remarkable journey from seed to harvest. Join us on this exploration of the fields that bind us all, as we cultivate a deeper understanding and appreciation for the intricate dance of life on the farm.

I warmly welcome the authors with their contributions that can meet the practical appliances with an integrated/ convergent approach. I wish, with all your support I could see a very bright prospects for Krishi Netra magazine as an eye opener in serving the needs of the farming community.

We look forward for your valuable feedback!
For any questions/ suggestions/ concerns, please contact us: krishinetra@gmail.com
Thank you.

Editor-in-Chief
Gangisetty Srikanth Kumar

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# Blockchain Technology – Integrated Seed Supply Chain System

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## ABSTRACT

Seeds are the foundation of agricultural productivity and ensuring their quality, purity, and authenticity is essential for achieving sustainable agriculture and global food security. However, conventional seed supply chains face several challenges, including poor traceability, record manipulation, dependence on intermediaries, quality deterioration, and lack of transparency. Blockchain technology offers a promising solution by providing a decentralized, transparent, immutable, and traceable digital ledger that securely records every transaction across the seed supply chain. This paper discusses the working principles of blockchain, its major types, and its key characteristics with emphasis on their role in strengthening seed quality assurance. The article also highlights the implementation of a blockchain-based seed distribution system in Jharkhand, the first Indian state to adopt this technology for transparent subsidized seed distribution and farmer authentication. Overall, blockchain-enabled seed supply systems represent an innovative pathway toward a secure, reliable, and transparent agricultural ecosystem that strengthens food security and promotes sustainable agricultural development.


**Keywords:** Block chain, transparency, traceability, immutability, decentralization

## INTRODUCTION

Every harvest begins with a seed, and the future of food security depends on its quality, purity, and authenticity. In an era where sustainable agriculture has become a global priority, the United Nations introduced the 17 Sustainable Development Goals (SDGs) to build a hunger-free and sustainable world by 2030. Among these, SDG 2 – Zero Hunger promotes food security and sustainable agriculture, while SDG 9 – Industry, Innovation and Infrastructure encourages the adoption of advanced technologies for sustainable development (United Nations in India).

Seeds are the foundation of agricultural productivity, carrying the genetic potential that determines crop yield, quality, and resilience. Although seed certification systems are designed to maintain varietal purity and ensure quality standards, conventional methods often face challenges such as limited traceability, lack of transparency, and risks of data manipulation.

In this digital age, blockchain technology is emerging as a revolutionary solution for strengthening seed quality assurance. With its decentralized, transparent, and tamper-proof nature, blockchain enables secure tracking of every stage in the seed supply chain—from production and certification to storage and distribution. By enhancing trust, traceability, and accountability, blockchain-enabled seed quality assurance offers a smarter and more reliable pathway toward sustainable agriculture and global food security.

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## CONVENTIONAL SEED SUPPLY CHAIN

The conventional seed supply chain works accordingly as in fig 1. This system of seed supply has a lot of demerits such as quality deterioration risk, manipulation of records, dependence on intermediaries, higher costs and information asymmetry which can be overcome by the inclusion of blockchain technology in this supply system.

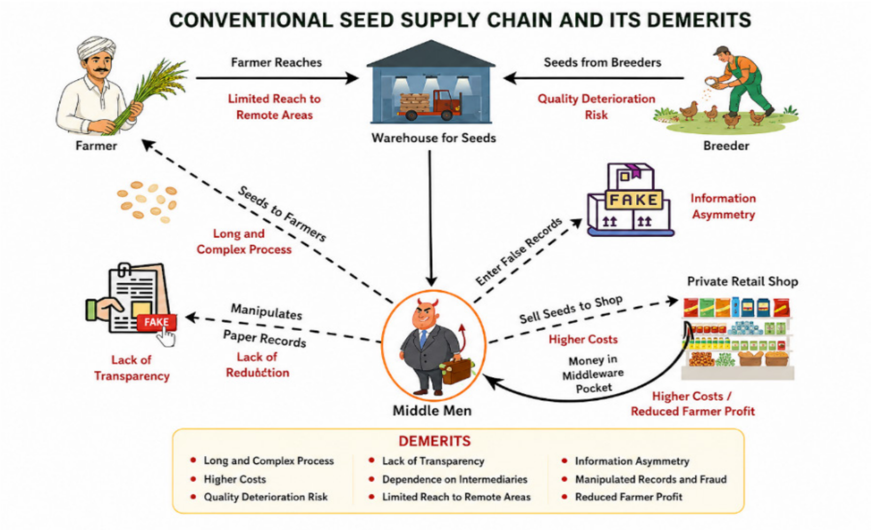


Fig:1 (Ahuja *et al.,* 2024)

## BLOCKCHAIN TECHNOLOGY

Blockchain is a distributed ledger maintaining a continuously growing list of data records that are confirmed by all of the participating nodes. The data is recorded in this public ledger in a form of blocks of valid transactions, and this public ledger is shared and available to all nodes (Raikwar *et al.,* 2019). A blockchain block consists of three major components (fig 2): The data stored within the block, the hash value of the previous block, and its own unique hash value, which together create a secure and interconnected chain structure (Lightwala *et al.,* 2022). GeeksforGeeks (2025) explained that a hash function is a mathematical function that converts input data of any size into a fixed-length output value known as a hash value or hash code.

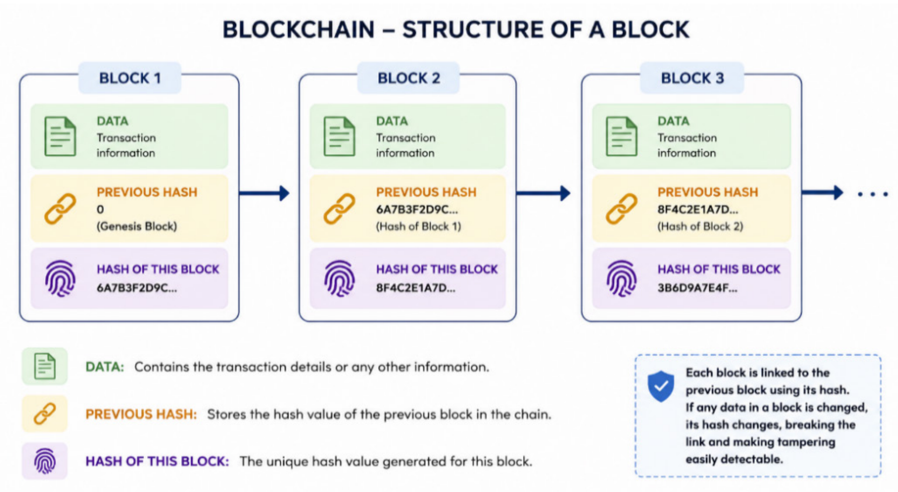


Fig: 2

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TYPES OF BLOCKCHAIN

There are three major types of blockchain (fig 3). They are public blockchain, private blockchain and consortium blockchain (FAO & ITU, 2019).

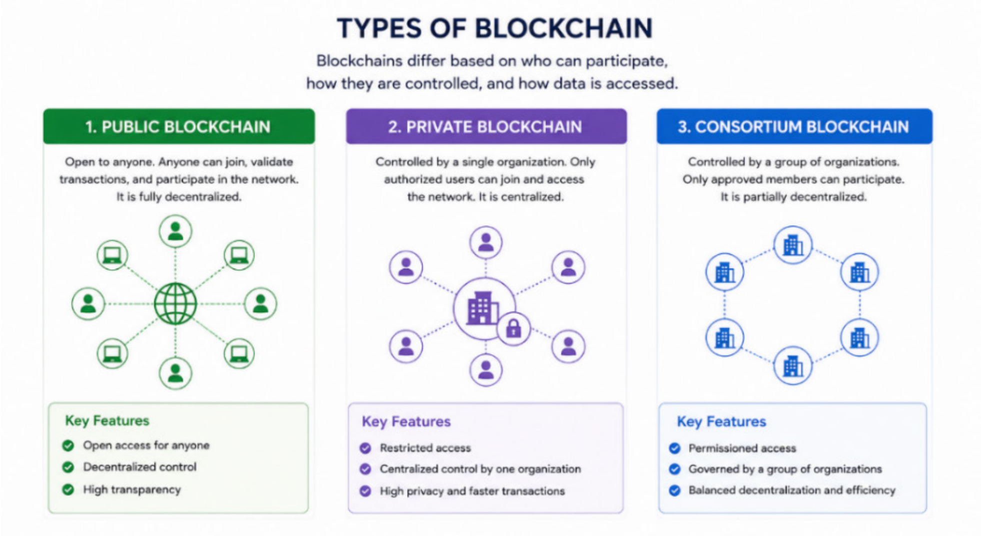


Fig: 3

CHARACTERISTICS OF THE BLOCKCHAIN TECHNOLOGY

The important characteristics of the blockchain technology are decentralization, traceability, immutability and transparency (Li, 2025).

**1. Decentralization:** Contemporarily, the centre gathers and controls flow of information in a system. This system is not only costly but also highly susceptible to security breaches and information loss. When supplier records become unavailable or lost farmers as end users are unable to link seed related information with the agricultural commodity supply chain, which ultimately leads to break in upstream traceability. As a result, it reduces market demand and credibility.

Blockchain technology solves this issue through a decentralized framework in which data is shared across multiple network participants. Within blockchain the information are no longer dependent on a single participant in supply chain. Even if one participant lost the data, identical records remain securely with other participants.

**2. Traceability:** Traceability refers to the capability of blockchain technology to track the origin and movement of data through its linked chain structure while permanently storing historical records from the genesis block onward. The traceability feature of blockchain enables consumers to obtain accurate information regarding the production location, cultivation period, and history of a product, thereby improving product reliability and consumer confidence.

**3. Immutability:** Immutability refers to the characteristic of blockchain in which stored records cannot be modified once they are verified and added to the network through consensus among participating nodes. Cryptographic techniques securely link each block, making unauthorized modifications highly difficult,

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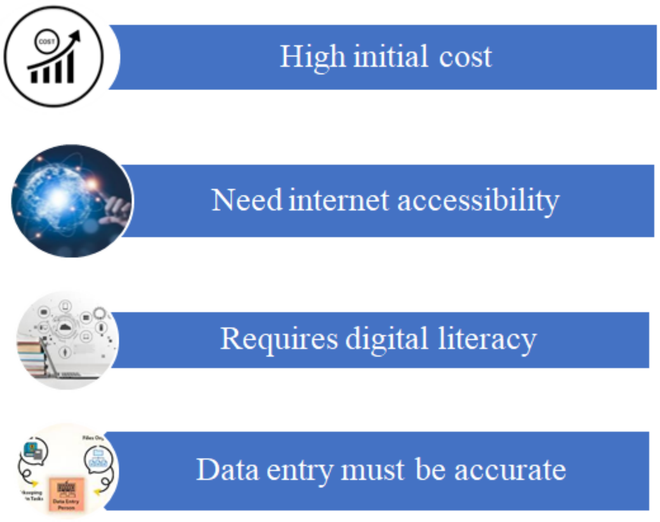
complex, and costly. Even a minor modification in the input data produces a completely different hash output. Because each hash value is uniquely linked to its original data, any alteration can be easily detected. Thereby greatly improving data reliability and trustworthiness in the seed supply chain.

**4. Transparency:** Blockchain technology records each transaction using asymmetric encryption enabling all participants in the network to view and verify transaction details. This creates a highly transparent and accessible system of data management. In the event of disputes or inconsistencies, relevant information can be retrieved quickly and efficiently by authorized participants. Since every transaction is permanently recorded and can be monitored at any stage, blockchain establishes a strong framework of accountability and trust among users involved in the network.

## IMPLEMENTATION OF BLOCKCHAIN TECHNOLOGY

Jharkhand became the first Indian state to implement a production-grade blockchain-based seed distribution system to improve transparency and efficiency in agriculture. The system registers farmers using Aadhaar and mobile numbers, and seed distribution is authenticated through OTP verification. Blockchain enables real-time monitoring of seed distribution, including crop varieties, quantities distributed, and farmer purchase records. The initiative supports transparent delivery of subsidized seeds and helps create a reliable farmer database for better implementation of agricultural and horticultural schemes. The system is expected to reduce pilferage and allow farmers to verify the quality and quantity of seeds received (Asian News International, 2022).

## LIMITATIONS IN BLOCKCHAIN TECHNOLOGY




## CONCLUSION

Blockchain is not merely a technological innovation. It’s the foundation for a smarter and more transparent agricultural future which can bridge the gap between breeders and farmers by creating a secure and tamper-proof seed supply system. As the world faces increasing challenges related to food security and agricultural sustainability, the adoption of blockchain technology in seed supply chain offers promising path

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forward. Traceability, accountability, and transparency can revolutionize the agricultural sector, empowering farmers while strengthening consumer confidence. The seed of tomorrow may not only grow crops but also cultivate trust through blockchain-enabled agriculture.

“If agriculture goes wrong, nothing else will have a chance to go right”

**-M. S. Swaminathan**

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# Importance of Plant Growth Regulators (PGRs) in Cucurbits

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**Abstract**

Plant growth regulators (PGRs) play a crucial role in improving growth, flowering, and yield in cucurbit crops.They help regulate sex expression, enhance fruit set, and improve overall productivity. Proper use of PGRs leads to better quality fruits and efficient crop management.

**Introduction:**

Cucurbits are an important group of vegetable crops belonging to the family Cucurbitaceae, including cucumber, pumpkin, bottle gourd, and bitter gourd. These crops are highly sensitive to environmental conditions, particularly temperature and photoperiod, which influence flowering and sex expression. Plant growth regulators (PGRs) are organic substances that modify physiological processes at low concentrations and are widely used to enhance crop performance. In cucurbits, PGRs such as auxins, gibberellins, ethylene, and growth retardants play a vital role in regulating vine growth, inducing female flowers, improving fruit set, and reducing flower drop. Their application helps in increasing yield, improving fruit quality, and ensuring uniform growth, making them essential tools in modern cucurbit cultivation.

**Importance of Plant Growth Regulators (PGRs) in Cucurbits**

- Plant growth regulators (PGRs) are chemical substances that influence plant physiological processes at very low concentrations. In cucurbits, which are monoecious crops bearing separate male and female flowers, PGRs play a decisive role in modifying growth, flowering behavior, and yield potential.

**Regulation of Sex Expression:**

- Cucurbit crops naturally produce more male flowers than female flowers, which limits yield. Application of ethylene-releasing compounds like ethephon and auxins increases the proportion of female flowers (gynoecy), thereby significantly enhancing fruit production. Conversely, gibberellins promote maleness, which can be useful in hybrid seed production.

**Improvement in Flowering Behavior:**

- PGRs help in early initiation of flowering and reduce the node number at which first female flowers appear. This leads to early fruiting and shortens the crop duration. Uniform flowering also helps in synchronized harvesting.

**Enhanced Fruit Set and Reduced Flower Drop:**

- Auxins such as NAA and 2,4-D improve fruit set by preventing premature abscission of flowers and

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young fruits. They strengthen the fruit retention capacity of plants, reducing losses during critical stages.

**Induction of Parthenocarpy:**

- Certain PGRs like auxins and gibberellins induce parthenocarpy (development of fruits without fertilization), especially in cucumber. This results in seedless fruits with better market preference and higher economic value.

**Control of Vegetative Growth:**

- Excessive vegetative growth in cucurbits can reduce yield. Growth retardants such as CCC (Cycocel) and MH (Maleic hydrazide) help control vine elongation and divert plant energy toward reproductive growth, improving yield efficiency.

**Increase in Yield and Productivity:**

- Through better sex expression, improved fruit set, and reduced drop, PGRs significantly increase the number of marketable fruits per plant, leading to higher overall yield.

**Improvement in Fruit Quality:**

- PGRs enhance fruit size, shape, color, and uniformity. They also improve internal quality parameters such as total soluble solids (TSS), sugar content, and texture, which increases consumer acceptance.

**Early Harvesting and Market Advantage:**

- Application of PGRs can advance flowering and fruit maturity, enabling farmers to harvest earlier and capture better market prices.

**Stress Management:**

- PGRs help cucurbit plants tolerate abiotic stresses such as drought, salinity, and temperature extremes by regulating physiological processes like stomatal activity and water balance.

**Better Nutrient Utilization:**

- PGRs improve enzyme activity and metabolic efficiency, enhancing nutrient uptake and assimilation, which supports overall plant vigor and productivity.

**Role in Hybrid Seed Production:**

- Gibberellins are used to increase male flower production, while ethylene-releasing compounds promote female flowers. This manipulation is essential for controlled pollination in hybrid seed production programs.

**Economic Benefits:**

- Efficient use of PGRs reduces crop losses, improves yield and quality, and ultimately increases farmers' income with relatively low investment.

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# Nature's Tiny Pharmacists: Healing Secrets from the Insect World

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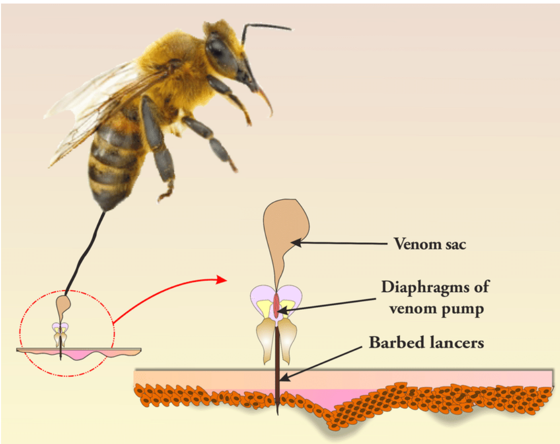
Medicinal insects are the insects that are used to prevent or treat diseases in humans. For thousands of years, different cultures around the world have used insects and their products as natural medicine. This practice is known as entomotherapy.

**Therapeutic Benefits:** Insects are valuable sources of natural medicine due to their high concentration of nutrients and active ingredients, which include:

- **Antimicrobial and Antibiotic Properties:** Used to fight infections.
- **Antitumor Activity:** Studied for cancer treatment applications.
- **Wound Healing:** Enabled by maggot therapy and certain insect oils.
- **Anti-inflammatory Effects:** Effective for managing conditions like arthritis

The following insects are used in manufacture of different drugs and used in curing human ailments.

1. **Honey bees:** The stings of honey bee are said to have remedial value in the treatment of arthritis and rheumatism. A specific medicine (Homeopathic), Apis is extracted from the honey bees by digesting the excited bees in alcohol and is used against certain diseases like urinary irritations, diphtheria *etc*. The honey is also used in wound healing, cough suppressant, antibacterial agent. The propolis acts as antimicrobial and will boost the immune system.



Honey bee sting (Qeios, 2026)


Bee pollen collection by worker honey bee
Burlesons (2026)

2. **Blister beetles:** Cantheridin is a substance found in the blister beetle, *Lytta vesicatoria* and is useful internally treating certain urinary diseases and externally as a vesicant and counter irritant. It is also probably the world's best known and most widely abused aphrodisiac. It is also known to be a tonic for hair. However,

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it has profound physiological effects on human body and its use in medicine is how banned because of its high toxicity.

Blister beetle, *Lytta vesicatoria*
(Meloidae.com, 2026)

3. **Blatta medicines:** Dr. William Boericke, a renowned homeopath, mentioned two drugs that are prepared from cockroaches, *Blatta americana* for urinary disorders like relieving from the burning sensation during urination, reducing the kidney inflammation, and also useful in curing extreme tiredness, and low vitality and also general physical exhaustion, recovery from edematous condition. *Blatta orientalis* is used for curing respiratory disorders like asthama, bronchitis, chronic cough.


*Blatta Americana* (Sanita ambientale, 2026)


*Blatta orientalis* (Obseration.org, 2026)

4. ***Ophiocordyceps sinensis*:** Caterpillar fungus it is prepared from caterpillars of *Ophiocordyceps sinensis* is used as a tonic by the Chinese athletes for strengthening and rejuvenating the body, to relieve stress, protect lungs and strengthen immune system. Due to its medicinal properties, it has been called the Chinese medicine for eternal youth"

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5. **Alleppo galls**: These galls also called as Oak galls formed on oak trees. The galls are caused by cynipid wasps (Cynipidae: Hymenoptera). They are rich in tannins. These tannins are having high medicinal value along with the gallic acid and ellagic acid. In Europe and West Asian countries, these galls are used as a powerful astringent tonic and antidote for certain poisons and also used for the antimicrobial activity to prevent infection around the human wounds. These secretions also useful to cure the chronic diarrhea, intestinal infections, and excessive mucus secretion in the gut.


Alleppo oak galls (Audrey J. Brandt, 2026)

6. **Maggot therapy**: Use of maggots of certain flies to clean wounds and promote healing has been used for centuries in some societies. Allantoin is a substance isolated from the secretions of fly maggots which seems to have properties of healing deep wounds.

7. **Ants (*Polyrhachis dives*):** This is the species of weaver ant. It is traditionally used in East Asia medicine especially in china. The whole ant or its secretions consists of proteins, amino acids, minerals like zinc, iron and other bioactive compounds. The secretions having the medicinal properties like immunomodulatory, anti-inflammatory, antioxidant, anti-fatigue and also having aphrodisiac and hepatoprotective activity.


***Polyrhachis dives***, (Wikipedia, 2026)

8. **Grasshoppers:** Grasshoppers are used as diuretic, anti-inflammatory, and also arthritis management such as joint pain and stiffness. They are having antioxidant properties.
9. **Wasps:** Wasp venom is noted for containing antibiotic and potential antitumor properties

**Other Applications**

✓ **Sutures:** Soldier ants (Army ants) have been used to close wounds due to their strong mandibles and the antibiotic properties in their saliva.

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Using ants as sutures (Reddit, 2026)

✓ **Nutraceuticals:** Insects, such as crickets, are consumed for high-value protein and probiotic content.

**Conclusion**

While many insects offer therapeutic value, there are potential risks, such as the transmission of parasites like nematodes if certain species, such as grasshoppers, are not prepared correctly. Further research is needed to fully explore the medicinal potential of many insect species.

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# Nutri-Gardens: A Sustainable Path to Better Health, Nutrition and Food Security

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**Abstract**

Nutri-gardens, popularly known as Poshan Vatikas, are household production systems designed to provide families with a regular supply of fresh vegetables, fruits, leafy greens, herbs, and tuber crops. They offer an effective and affordable approach to improving dietary diversity, nutritional security and household food availability. In recent years, the increasing prices of fresh produce, concerns over pesticide residues, and the growing prevalence of micronutrient deficiencies have highlighted the need for sustainable household food production. By utilizing available spaces, such as backyards, terraces, rooftops, balconies, and containers, families can cultivate a variety of nutrient-rich crops throughout the year using eco-friendly cultivation practices. In addition to enhancing access to safe and nutritious food, nutri-gardens reduce household expenditure, encourage recycling of organic waste through composting, improve soil health, and generate additional income from surplus produce. They also strengthen the role of women in household nutrition management and promote environmental sustainability by reducing dependence on external food sources and chemical inputs. With appropriate crop planning, efficient use of space, and the adoption of organic management practices, nutri-gardens can play a significant role in addressing hidden hunger and building healthier, more resilient communities.

**Keywords:** *Dietary diversity, Food security, Hidden hunger, Home gardening, Household nutrition, Nutri-garden, Organic farming, Poshan Vatika, Sustainable agriculture*

## Introduction

Ensuring access to safe, nutritious, and affordable food is fundamental to achieving good health and improving quality of life. Vegetables, fruits, leafy greens, and root crops are indispensable components of a balanced diet because they supply essential vitamins, minerals, dietary fiber, antioxidants, and numerous bioactive compounds required for normal growth, immunity, and disease prevention. Nutrition experts recommend the regular consumption of a diverse range of vegetables and seasonal fruits to meet daily nutritional requirements and reduce the risk of micronutrient deficiencies.

Despite advances in agricultural production, many households continue to face challenges in accessing fresh and nutritious food. Rapid urbanization, shrinking landholdings, changing food habits, rising prices of vegetables and fruits, and concerns about pesticide residues have affected the availability and affordability of healthy foods. At the same time, deficiencies of essential micronutrients, such as iron, calcium, zinc, and vitamins A and C, continue to contribute to "hidden hunger," particularly among women and children.

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**Why Nutri-Gardens Matter**

Nutri-gardens help families overcome nutritional deficiencies while promoting food security and environmental sustainability. By cultivating various seasonal fruits and vegetables using organic methods, households can maintain a continuous supply of fresh produce throughout the year.

Nutri-gardens provide a practical, low-cost, and sustainable solution to these challenges by enabling households to grow a diverse range of crops within their own premises. Gardens can be established in backyards, kitchen surroundings, terraces, rooftops, balconies, or containers, depending on the availability of space. A well-planned nutri-garden ensures a continuous supply of fresh produce throughout the year, while reducing dependence on market purchases.

**Major Benefits of Nutri-Gardens**

Beyond improving dietary intake, nutri-gardens offer multiple environmental, economic, and social benefits that contribute to sustainable household development in the long term. By recycling biodegradable kitchen and garden waste into compost, these gardens improve soil fertility while reducing the amount of household waste. Efficient water use, crop diversification, and minimal dependence on synthetic fertilizers and pesticides make nutri-gardens an environmentally responsible system for food production.

- The regular availability of fresh, nutrient-dense vegetables and fruits enhances dietary diversity and helps address micronutrient deficiencies among family members.
- From an economic perspective, nutri-gardens reduce expenditure on purchasing vegetables and fruits, thereby improving household income. Surplus produce can be marketed locally, providing an additional source of income for the families.
- Home gardening also strengthens the role of women in household nutrition management, decision-making, and income generation, thereby contributing to their economic and social empowerment of women. Furthermore, gardening encourages active family participation, promotes physical activity, and provides recreational and therapeutic benefits by reducing stress and enhancing mental health.
- Collectively, these diverse benefits make nutri-gardens an effective and sustainable approach for improving nutrition, food security, environmental health, and household resilience.

**<u>Types of Nutri-Gardens</u>**

**1. Large-Sized Gardens (Above 500 sq. m)**

Suitable for vegetables, fruits, medicinal plants, and ornamental plants.

<u>Recommended Crops:</u>Vegetables: Brinjal, Tomato, Okra, Bitter gourd, Bottle gourdFruits: Mango, Guava, Sapota, Papaya, Banana, Amla, Lemon

**2. Medium-Sized Gardens (150–200 sq. m)**

It is ideal for growing multiple seasonal vegetables and a few fruit plants.

<u>Recommended Crops:</u>Tomato, Brinjal, Chilli, Okra, Beans, Radish, Cabbage, Cauliflower, Ridge gourdFruit

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Plants: Lemon, Papaya, Guava

**3. Small-Sized Gardens (Below 150 sq. m / Terrace / Balcony)**

It is suitable for compact spaces and container gardening.

Recommended Crops:

- Coriander, Mint, Spinach, Amaranthus, Fenugreek, Curry leaves, Green chilli

**Nutritious Vegetable and Fruit Varieties**

- Leafy Greens like Palak (Spinach) Thotakura (Amaranthus), Methi (Fenugreek), Gongura (Roselle leaves), Curry leaves and Moringa leaves

Nutritional Importance**:** Rich in iron, calcium, folic acid, and Vitamin A.

- Root and Tuber Crops like Carrot, Radish, Beetroot, Sweet potato, Yam, Taro

Nutritional Importance**:** Good source of energy, fiber, beta-carotene, and minerals.

- Common Vegetables like Tomato, Brinjal, Okra, Cluster beans, French beans, Bottle gourd, Ridge gourd, Bitter gourd, Snake gourd, Ash gourd, Cucumber, Pumpkin, Green peas, Onion, Garlic.

Nutritional Importance**:** Provides vitamins, antioxidants, fiber, and phytonutrients.

- Fruit Crops Suitable for Home Gardens

| Fruit | Variety | Fruit | variety |
|---|---|---|---|
| Sapota | Kalipatti | Banana | Dwarf Cavendish, Robusta |
| Amla | NA-7, Krishna | Guava | Allahabad Safeda, Lucknow-49 |
| Lemon | Balaji, Kagzi Lime | Papaya | Red Lady, Pusa Delicious |
| Pomegranate | Bhagwa | Mango | Banginapalli, Alphonso, Totapuri |
| Drumstick | PKM-1, PKM-2 | Water Apple | Thai Red and Thai White |

Nutritional Importance**:** Rich in Vitamin C, Vitamin A potassium, and antioxidants.

**Seasonal Crop Planning for Indian Conditions**

- ***Summer (February–May)***

Brinjal, Cucumber, Ridge gourd, Bottle gourd, Pumpkin, Bitter gourd, Watermelon

- ***Monsoon (June–September)***

Okra, Chilli, Beans, Gourds, Cowpea, Cluster beans

- ***Winter (October–January)***

Radish, Carrot, Beetroot, Tomato, Cabbage, Cauliflower, Coriander, Spinach, Peas

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- ***Year-Round Crops***

Banana, Papaya, Curry leaves, Drumstick, Lemon

**Backyard Garden Layout Ideas**

A productive nutri-garden requires proper design and efficient space utilization.

- Block Planting

Growing in blocks minimizes empty spaces, reduces the number of weeds, and increases the yield. This is suitable for Carrot, Beetroot, Leafy greens, Garlic.

- Vertical Gardening

Bamboo poles, trellises, or fences are used to grow climbers.

Best Climbers: Cucumber, Pole beans, Bottle gourd, Ridge gourd, Bitter gourd, Snake gourd

Vertical gardening saves space and improves the air circulation.

- Companion Planting

Growing vegetables with flowers and herbs helps to naturally control pests.

Examples: 1.Tomato + Marigold, 2. Carrot + Radish, 3. Cabbage + Mint, 4. Brinjal + Coriander

- Layered Gardening

Tall crops at the back: Papaya, BananaMedium crops in middle: Tomato, BrinjalShort crops in front: Spinach, Coriander

This maximizes the utilization of sunlight.

**Precautions in Cultivation**

- Choose quality seeds suited to the local climate and recycle kitchen waste into compost.
- Prepare fertile soil with compost: Farmyard manure (FYM), Vermicompost, Kitchen compost to improve soil fertility and health.
- Irrigation: Summer: Water every 2–3 days, Winter: Water every 5–7 days, and avoid water stagnation.

Sunlight: Select a sunny location for the plant. Most vegetables require 5–6 h of sunlight daily.

Weed management: Weeds should be removed regularly to reduce nutrient competition.

Crop Rotation: Rotate crops to reduce pest and disease buildup. Example: Leafy greens → Legumes → Fruiting vegetables

Organic Pest Management: Avoid chemical pesticides in home gardens. Natural sprays, such as neem oil (4

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ml), tea tree oil (2 ml), and soap solution, were used. Mix in 1 litre water and spray weekly

Other eco-friendly methods: Yellow sticky traps, Wood ash application, Garlic-chilli spray

**Nutritionally rich common vegetables:**

- Carbohydrates: Sweet potato, Yam, Beetroot. Proteins: Beans, Peas, Soybean, Cowpea,
- Calcium: Spinach, Fenugreek, Moringa leaves,
- Iron: Spinach, Mint, Gongura, Amaranthus,
- The vitamin A sources were carrot, pumpkin, and papaya; vitamin C sources were tomato, cabbage, lemon, and guava; and phosphorus sources were onion, garlic, and peas.

A diverse nutri-garden helps prevent hidden hunger, especially deficiencies in iron, calcium, and Vitamin A.

**Conclusion:**

A nutri-garden is much more than a small vegetable patch; it is a pathway to better health, improved nutrition, financial savings, and sustainable living. Even a small terrace, balcony, or backyard can produce fresh and chemical-free food with proper planning and execution. By growing Indian vegetables and fruit varieties at home, families can ensure year-round access to nutritious food while becoming more self-reliant and environmentally aware.


"Grow your food, nourish your family, and cultivate health from your own backyard."


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# Region-specific Crop Coefficients: A Foundation for Scientific Irrigation Scheduling in Tamil Nadu

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## Abstract

Tamil Nadu is one of the most water-stressed states in India, where agriculture depends on limited rainfall, declining groundwater resources, and increasing competition for water from domestic and industrial sectors. Efficient utilization of available water resources has therefore become essential for ensuring agricultural productivity and sustainability. Among the various tools used for scientific irrigation scheduling, the **crop coefficient (Kc)** plays a crucial role in estimating crop water requirements accurately. Developing **region-wise crop coefficients** for Tamil Nadu is an important step toward improving irrigation efficiency and sustainable water resource management.

## Keywords

Crop Coefficient (Kc), Reference Evapotranspiration (ETo), Crop Water Requirement, Irrigation Scheduling, Water Use Efficiency, Precision Agriculture, Lysimeter, Agro-climatic Zones, Climate Change, Tamil Nadu, Sustainable Water Management.

## Introduction

Crop water requirement (ETc) is the amount of water needed by a crop to compensate for water lost through evapotranspiration. It is calculated using the equation:

$$\mathbf{ETc = ETo \times Kc}$$

where:

- **ETc** = Crop evapotranspiration (mm/day)
- **ETo** = Reference evapotranspiration (mm/day)
- **Kc** = Crop coefficient

The crop coefficient reflects the combined effects of crop characteristics, canopy development, crop growth stage, and local climatic conditions. Traditionally, Kc values recommended by the Food and Agriculture Organization (FAO-56) are widely used. However, these generalized values may not accurately represent the diverse agro-climatic conditions prevailing across Tamil Nadu.

## Need for Region-wise Crop Coefficient Estimation

Tamil Nadu encompasses seven distinct agro-climatic zones, each characterized by different rainfall patterns, temperatures, humidity levels, wind speed, soil types, and cropping systems. These variations

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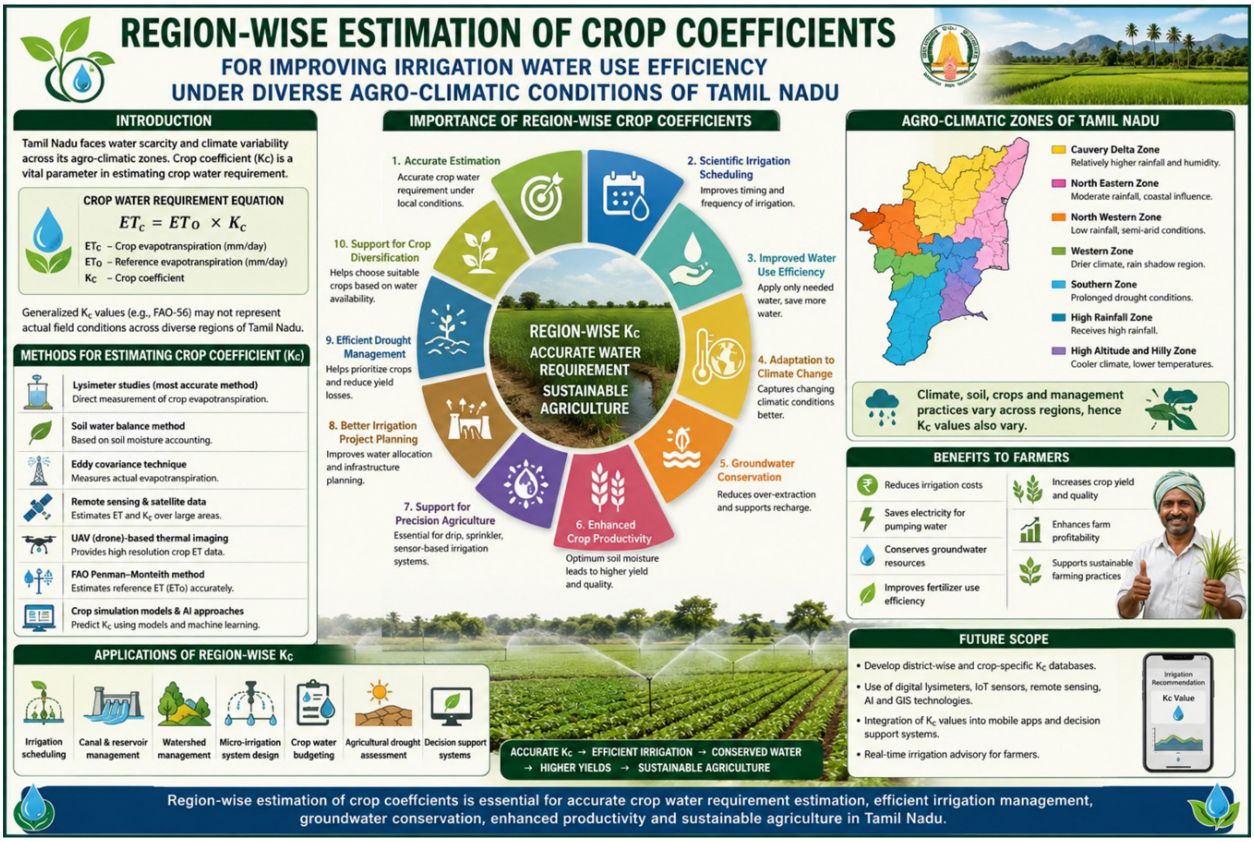
significantly influence crop evapotranspiration and crop coefficient values.

For example:

- Delta districts receive relatively higher rainfall and humidity.
- Western districts experience dry climatic conditions.
- Southern districts often face prolonged drought.
- Hilly regions possess comparatively cooler climates.

Therefore, adopting a single Kc value for the entire state may lead to inaccurate estimation of crop water requirements.




**Importance of Region-wise Crop Coefficients**

**1. Accurate Estimation of Crop Water Requirement**

Region-specific Kc values enable precise estimation of evapotranspiration for crops grown under local climatic conditions. This helps farmers apply the exact quantity of irrigation water required during different growth stages.

**2. Scientific Irrigation Scheduling**

Accurate Kc values facilitate preparation of efficient irrigation schedules based on crop growth stages rather than fixed irrigation intervals. This improves irrigation timing and reduces water wastage.

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**3. Improved Water Use Efficiency**

Agriculture accounts for nearly 80% of freshwater consumption in Tamil Nadu. Region-wise Kc estimation allows irrigation water to be applied according to actual crop demand, thereby enhancing water use efficiency and conserving scarce water resources.

**4. Adaptation to Climate Change**

Climate change is altering rainfall distribution, temperature, and evapotranspiration patterns across Tamil Nadu. Locally developed crop coefficients can capture these changing climatic conditions more accurately than generalized FAO values, making irrigation planning more resilient.

**5. Groundwater Conservation**

Over-extraction of groundwater is a major concern in several districts of Tamil Nadu. Accurate estimation of crop water requirements reduces unnecessary groundwater pumping, thereby contributing to groundwater recharge and sustainable resource management.

**6. Enhanced Crop Productivity**

Both deficit and excess irrigation adversely affect crop growth and yield. Region-specific crop coefficients help maintain optimum soil moisture throughout the crop growth period, leading to improved crop performance and higher yields.

**7. Support for Precision Agriculture**

Modern irrigation technologies such as drip irrigation, sprinkler irrigation, sensor-based irrigation, and automated irrigation systems require accurate crop coefficients. Region-wise Kc values enhance the efficiency of these precision irrigation systems.

**8. Better Irrigation Project Planning**

Government agencies use crop water requirements while designing irrigation projects, canal operation schedules, reservoir management plans, and watershed development programmes. Region-specific Kc values improve the accuracy of water allocation planning.

**9. Efficient Drought Management**

During drought years, irrigation water must be allocated judiciously. Reliable regional Kc values help prioritize irrigation based on actual crop demand, minimizing yield losses under limited water availability.

**10. Support for Crop Diversification**

Knowledge of water requirements through accurate Kc estimation helps farmers choose crops that are better suited to local water availability, thereby promoting sustainable cropping patterns.

**Agro-climatic Diversity of Tamil Nadu**

Tamil Nadu consists of several agro-climatic zones, including:

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- Cauvery Delta Zone
- North Eastern Zone
- North Western Zone
- Western Zone
- Southern Zone
- High Rainfall Zone
- High Altitude and Hilly Zone

Each zone exhibits unique climatic characteristics influencing crop evapotranspiration. Consequently, crops such as rice, sugarcane, maize, cotton, banana, coconut, vegetables, and pulses require different Kc values under different regional conditions.

**Methods for Estimating Region-wise Crop Coefficient**

Crop coefficients can be estimated using several scientific approaches:

- Lysimeter studies
- Soil water balance method
- Eddy covariance technique
- Remote sensing and satellite observations
- UAV (drone)-based thermal imaging
- FAO Penman–Monteith method
- Crop simulation models
- Machine learning and artificial intelligence approaches

Among these, weighing lysimeters provide the most accurate direct measurement of crop evapotranspiration and are considered the standard method for determining crop coefficients.

**Conclusion**

The estimation of **region-wise crop coefficients** is essential for improving irrigation water management in Tamil Nadu. Due to considerable variations in climate, soil, and cropping systems across the state's agro-climatic zones, generalized crop coefficient values often fail to represent actual field conditions. Developing location-specific Kc values enables accurate estimation of crop water requirements, enhances irrigation efficiency, conserves groundwater, increases crop productivity, and supports sustainable agriculture. Region-wise crop coefficient estimation is therefore a critical component of climate-smart irrigation and efficient water resource management, ensuring long-term agricultural sustainability in Tamil Nadu.

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# Seed Sector Reforms and Agribusiness Growth: A Public–Private Partnership Perspective

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## 1. Introduction

Agriculture remains a cornerstone of the Indian economy, supporting livelihoods, food security, and rural development. Within agriculture, the horticulture sector has emerged as one of the fastest-growing and most commercially vibrant subsectors. India ranks among the world's leading producers of fruits, vegetables, spices, flowers, and plantation crops, with horticultural production exceeding food grain production in recent years. The sector contributes substantially to agricultural gross value added (GVA), employment generation, nutritional security, and export earnings.

The success of horticultural production depends heavily on the availability of quality seeds and planting materials. Unlike cereal crops, horticultural crops are characterized by high market value, quality sensitivity, perishability, and intensive input requirements. Farmers increasingly demand hybrid seeds, disease-resistant cultivars, climate-resilient varieties, and planting materials capable of meeting evolving market and consumer preferences. Consequently, seed systems have become a critical determinant of productivity, profitability, and competitiveness within horticultural value chains.

Traditionally, seed systems in India focused primarily on the multiplication and distribution of improved varieties developed by public research institutions. However, rapid commercialization, technological advancement, and globalization have transformed seed systems into complex market-driven ecosystems involving multiple stakeholders, including research organizations, seed companies, nurseries, farmer producer organizations (FPOs), agri-startups, distributors, retailers, and regulatory agencies. This transition reflects a broader shift from input-centric approaches toward integrated value chain models that emphasize efficiency, innovation, market responsiveness, and farmer empowerment.

Market-driven seed systems operate through coordinated networks that connect research, seed production, processing, quality assurance, marketing, distribution, and end-user adoption. Such systems encourage innovation, facilitate investment, improve access to quality planting materials, and strengthen linkages among actors across the value chain. Public-private partnerships (PPPs) have emerged as a particularly important mechanism for promoting these objectives by combining public-sector research capabilities with private-sector efficiency, investment, and market expertise.

The increasing adoption of digital technologies is further accelerating the transformation of seed systems. Mobile-based advisory platforms, artificial intelligence-driven forecasting tools, blockchain-enabled traceability systems, and e-commerce marketplaces are reshaping how seeds are produced, distributed, and marketed. These innovations are improving transparency, reducing transaction costs, and enhancing market access for farmers and agribusiness enterprises.

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Despite significant progress, several challenges continue to constrain the effectiveness of horticultural seed systems. High seed costs, counterfeit products, climate-related risks, inadequate storage infrastructure, fragmented markets, and regulatory bottlenecks remain persistent concerns. Addressing these issues requires coordinated efforts involving policymakers, research institutions, private enterprises, farmer organizations, and development agencies.

This paper examines the evolution of market-oriented seed systems in India's horticulture sector, with particular emphasis on value chain integration and public-private partnerships. It explores emerging business models, technological innovations, institutional arrangements, and policy interventions that are shaping the future of horticultural seed systems. The study also identifies key challenges and opportunities for strengthening sustainable and inclusive

| Indicator | Value |
|---|---|
| Horticulture Production | ~351 Million Tonnes |
| Area Under Horticulture | ~28 Million Hectares |
| Share in Agricultural GDP | ~30% |
| Global Rank in Fruits Production | 2nd |
| Global Rank in Vegetables Production | 2nd |

## 2. Literature Review

The development of efficient seed systems has long been recognized as a critical factor influencing agricultural productivity, food security, and rural economic development. According to Almekinders and Louwaars (2002), a well-functioning seed sector requires strong linkages among research institutions, seed producers, regulatory agencies, and farmers to ensure the continuous availability of quality planting materials. Their work emphasized the importance of integrating formal and informal seed systems to improve accessibility and sustainability.

Tripp and Rohrbach (2001) highlighted the role of policy and institutional frameworks in promoting seed enterprise development. Their study demonstrated that market-oriented seed systems perform more effectively when supported by enabling regulations, private-sector participation, and investment in seed infrastructure. The authors argued that liberalization of seed markets can stimulate innovation and improve the dissemination of improved varieties among farmers.

In the Indian context, Singh (2014) observed that seed systems play a strategic role in enhancing food security and agricultural competitiveness. The study emphasized that access to quality seeds significantly influences productivity growth, particularly in high-value agricultural sectors such as horticulture. Similarly, Chand (2017) identified improved seed adoption as a key component of strategies aimed at increasing farmers' income and strengthening agricultural value chains.

The expansion of horticulture has created new opportunities and challenges for seed system development. Birthal et al. (2005) reported that increasing market integration and vertical coordination in high-value agricultural commodities have encouraged the adoption of improved technologies, including hybrid seeds. Their findings indicated that stronger market linkages improve efficiency, reduce transaction costs, and enhance farmer participation in commercial agriculture.

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Recent studies have highlighted the growing importance of public-private partnerships in seed sector development. Spielman and Kennedy (2016) argued that collaborative approaches involving public research institutions and private enterprises accelerate varietal development, technology transfer, and commercialization. Public institutions contribute scientific expertise and germplasm resources, while private companies provide investment, marketing capabilities, and distribution networks.

Digital transformation has emerged as another significant theme in contemporary seed system literature. The World Bank (2019) emphasized the potential of digital technologies to improve transparency, traceability, and efficiency across agricultural value chains. Technologies such as mobile advisory platforms, artificial intelligence, blockchain systems, and e-commerce marketplaces are increasingly facilitating information exchange and market access for farmers.

Despite considerable progress, several studies continue to identify persistent constraints within seed systems, including high input costs, counterfeit products, regulatory bottlenecks, climate-related risks, and inadequate infrastructure. These challenges are particularly pronounced in developing countries where smallholder farmers often face limitations in accessing quality seeds, financial resources, and technical support.

Overall, existing literature suggests that sustainable seed systems require a combination of technological innovation, institutional coordination, market integration, and supportive policy interventions. The growing emphasis on public-private partnerships, digital agriculture, and value chain approaches reflects an evolving understanding of seed systems as dynamic agribusiness ecosystems rather than merely input delivery mechanisms. This study builds upon these perspectives by examining the role of market-driven seed systems in strengthening horticultural agribusiness value chains in India.

## 3. Importance of Seed Systems in Horticultural Development

Seeds and planting materials constitute the foundation of agricultural productivity and represent one of the most critical inputs in horticultural production systems. The quality of seeds directly influences crop establishment, yield potential, pest and disease resistance, product quality, shelf life, and marketability. In horticultural crops such as tomato, chilli, cabbage, cauliflower, cucumber, watermelon, onion, papaya, and various floriculture species, the adoption of improved varieties and hybrid seeds has significantly enhanced productivity and farm profitability.

The role of quality seed extends beyond productivity enhancement. Improved genetic material enables farmers to respond effectively to changing climatic conditions, emerging pest and disease pressures, and evolving consumer preferences. Climate-resilient varieties help reduce production risks associated with drought, heat stress, flooding, and erratic weather patterns. Similarly, disease-resistant hybrids contribute to lower pesticide use, reduced production costs, and improved environmental sustainability.

Horticultural markets increasingly demand uniformity, appearance, nutritional quality, and extended shelf life. These characteristics are largely determined by seed quality and varietal selection. Export-oriented horticulture enterprises, in particular, rely heavily on high-performance seeds capable of meeting stringent international quality standards. As a result, investment in improved seed systems has become an essential component of competitiveness in domestic and global markets.

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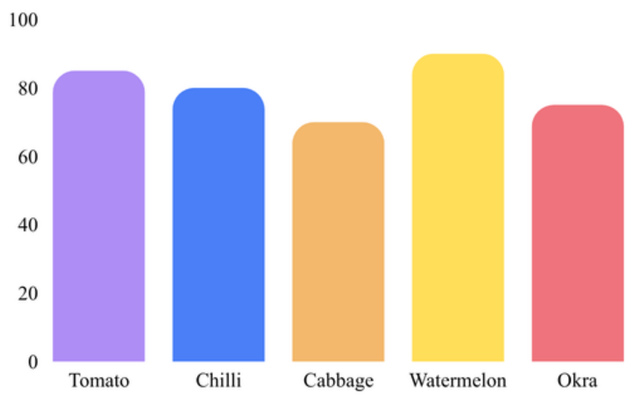
Quality seed systems also contribute to rural economic development by generating employment opportunities across seed production, nursery management, processing, packaging, logistics, retailing, and extension services. Seed enterprises support entrepreneurship among youth, women, and farmer producer organizations, creating additional income streams within rural economies. Furthermore, reliable access to quality seeds enhances farmers' confidence in adopting modern technologies and participating in commercial agriculture.

From a food and nutritional security perspective, improved horticultural seeds play a crucial role in increasing the availability and accessibility of fruits and vegetables. Enhanced production contributes to dietary diversification and supports public health objectives related to nutrition and food quality. As demand for horticultural products continues to rise due to urbanization, income growth, and changing consumption patterns, efficient seed systems become increasingly important for sustaining agricultural growth and meeting consumer needs.

Therefore, strengthening horticultural seed systems is not merely a technical requirement but a strategic necessity for achieving broader goals related to agricultural transformation, rural development, food security, and economic growth.




**Hybrid Seed Adoption in Major Vegetable Crops**

**4. Characteristics of Market-Driven Horticultural Seed Systems**

Horticultural seed systems differ substantially from conventional seed systems associated with cereal crops due to their commercial orientation, technological complexity, and quality sensitivity. The increasing integration of horticulture into domestic and international markets has accelerated the development of sophisticated seed supply networks designed to meet the evolving requirements of producers, processors, retailers, and consumers.

One of the defining characteristics of horticultural seed systems is the dominance of hybrid varieties. Crops such as tomato, chilli, brinjal, okra, cabbage, cauliflower, watermelon, and cucumber are largely cultivated using hybrid seeds because of their superior yield potential, uniformity, disease resistance, and market acceptance. The development and commercialization of hybrid technologies have created significant opportunities for private-sector participation, resulting in a highly competitive and innovation-driven seed industry.

Horticultural seed systems are also characterized by intensive technological requirements. Seed production often involves controlled pollination, maintenance of genetic purity, isolation protocols, nursery management, and specialized post-harvest handling procedures. These activities require technical expertise, infrastructure

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investments, and strict quality control mechanisms to ensure seed viability and performance.

Another important feature is the high economic value associated with horticultural seeds. Although seed costs constitute a relatively small proportion of total cultivation expenses, they have a substantial influence on crop performance and profitability. Consequently, farmers are generally willing to invest in premium-quality seeds when they perceive clear economic benefits. This market behavior encourages continuous innovation and product differentiation among seed companies.

The perishability of horticultural produce further increases the importance of seed quality. Poor-quality seeds can result in reduced germination rates, uneven crop establishment, inferior product quality, and significant post-harvest losses. Therefore, efficient seed systems play a critical role in ensuring consistency, reliability, and competitiveness throughout horticultural value chains.

Furthermore, horticultural seed systems increasingly rely on market intelligence and consumer-driven innovation. Seed companies continuously develop new varieties based on changing preferences related to appearance, taste, nutritional value, shelf life, and processing characteristics. This close alignment between seed development and market demand distinguishes horticultural seed systems from many traditional agricultural sectors.

**5. Seed Value Chain Framework in the Indian Horticulture Sector**

The horticultural seed industry functions through an interconnected value chain that links research institutions, seed producers, processing units, distributors, retailers, and farmers. The effectiveness of this value chain significantly influences the availability, affordability, and quality of seeds supplied to producers across diverse agro-climatic regions.

The value chain begins with research and varietal development. Public-sector institutions, including the Indian Council of Agricultural Research (ICAR), the Indian Institute of Horticultural Research (IIHR), and State Agricultural Universities (SAUs), play a critical role in developing improved varieties adapted to regional conditions. These institutions focus on enhancing productivity, disease resistance, climate resilience, and nutritional quality through conventional breeding and advanced biotechnological approaches.

Alongside public research organizations, private seed companies invest heavily in hybrid breeding programs and product innovation. Their efforts are primarily directed toward developing commercially viable hybrids that satisfy market demands and generate competitive advantages. The collaboration between public research institutions and private enterprises has become increasingly important in accelerating the commercialization of improved genetic materials.

Seed production represents the second major stage of the value chain. India has emerged as a global hub for hybrid vegetable seed production due to favorable agro-climatic conditions, skilled labor availability, and relatively low production costs. States such as Telangana, Andhra Pradesh, Karnataka, Maharashtra, Gujarat, and Tamil Nadu serve as major centers for seed multiplication activities.

Contract farming has become a widely adopted model for horticultural seed production. Under this arrangement, seed companies provide parent lines, technical guidance, quality standards, and assured procurement agreements, while farmers undertake seed multiplication activities. This model reduces market

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risk for producers while ensuring a stable supply of quality seeds for companies.

Following production, seeds undergo processing and quality assurance procedures. Activities such as cleaning, grading, drying, treatment, packaging, and germination testing are essential for maintaining seed quality and meeting regulatory standards. Seed certification agencies and quality control laboratories play a vital role in verifying compliance with prescribed standards and protecting farmers from substandard products.

The final stages of the value chain involve marketing, distribution, and retailing. Traditional distribution networks consisting of agri-input dealers and seed retailers continue to dominate seed sales. However, digital marketplaces, farmer producer organizations, franchise networks, and specialized horticultural nurseries are increasingly expanding market access and improving supply chain efficiency. The growing adoption of e-commerce platforms has further transformed distribution systems by enabling direct interaction between seed suppliers and end-users.

An efficient seed value chain ensures timely availability of quality planting materials, reduces transaction costs, facilitates innovation diffusion, and enhances the overall competitiveness of the horticulture sector. Strengthening linkages among value chain actors remains essential for achieving sustainable growth and improving farmer welfare.

| Indicator | Value |
|---|---|
| Total Horticulture Production (India) | ~351 Million Tonnes |
| Area Under Horticulture | ~28 Million Hectares |
| Share in Agricultural GDP | ~30% |
| Vegetable Seed Market Controlled by Private Sector | >75% |
| Hybrid Seed Adoption in Major Vegetables | 70-90% |
| Seed Replacement Rate in Vegetables | >90% |

| State | Major Seed Activities |
|---|---|
| Telangana | Hybrid vegetable seed production |
| Andhra Pradesh | Chilli, Tomato, Cucurbit Seeds |
| Karnataka | Hybrid vegetable seed production |
| Maharashtra | Onion & Vegetable Seeds |
| Gujarat | Contract Seed Farming |
| Tamil Nadu | Nursery & Seedling Enterprises |

### 6. Public-Private Partnerships in Horticultural Seed Systems

Public-private partnerships (PPPs) have emerged as a critical mechanism for strengthening horticultural seed systems in India. The increasing complexity of agricultural markets, rapid technological advancement, and growing demand for high-quality planting materials have necessitated collaborative approaches that leverage the strengths of both public and private institutions. PPPs facilitate resource sharing, risk mitigation, technology transfer, and market expansion, thereby contributing to the development of efficient and sustainable seed ecosystems.

Public-sector institutions continue to play a foundational role in seed system development through germplasm conservation, breeding research, varietal development, quality regulation, and extension services. Organizations

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such as the Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), National Seeds Corporation (NSC), and State Seed Corporations have historically contributed to the development and dissemination of improved crop varieties. These institutions provide the scientific knowledge and regulatory framework necessary for maintaining the integrity and reliability of seed markets.

The private sector complements these efforts through investments in research and development, hybrid seed technology, product commercialization, branding, logistics, and market expansion. Private seed companies possess the financial resources and operational flexibility required to rapidly respond to changing market demands and consumer preferences. Their participation has significantly accelerated the adoption of hybrid technologies and improved access to quality seeds across diverse production environments.

Several successful PPP models have emerged within India's horticulture sector. Contract seed production represents one of the most widely adopted models, wherein seed companies collaborate directly with farmers for the multiplication of hybrid seeds. Under these arrangements, companies provide parent materials, technical guidance, quality standards, and assured procurement mechanisms. This model creates stable income opportunities for farmers while ensuring a reliable supply of quality seeds for the industry.

Licensing agreements constitute another important form of partnership. Public research institutions increasingly license improved varieties and hybrids to private companies for commercial multiplication and distribution. Such collaborations accelerate technology dissemination and enhance the accessibility of publicly developed innovations to farming communities.

Farmer Producer Organizations (FPOs) are also emerging as significant partners within seed systems. By engaging in seed production, aggregation, processing, and marketing activities, FPOs strengthen local seed availability while improving bargaining power and reducing transaction costs for member farmers. Their participation contributes to greater inclusiveness and equity within seed value chains.

Overall, PPPs facilitate innovation, enhance investment flows, improve market efficiency, and support the development of resilient seed systems capable of addressing emerging agricultural challenges. Strengthening institutional collaboration remains essential for ensuring long-term sustainability and competitiveness within the horticulture sector.

| PPP Model | Benefits |
|---|---|
| Contract Seed Production | Assured farmer income |
| Licensing Agreements | Faster commercialization |
| Seed Village Programs | Local seed availability |
| FPO-led Enterprises | Better bargaining power |
| Nursery Partnerships | Quality seedlings |

**7. Digital Technologies and Agribusiness Innovation in Seed Systems**

Digital transformation is rapidly reshaping agricultural value chains worldwide, and the horticulture seed sector is no exception. The integration of advanced digital technologies is improving operational efficiency, enhancing market transparency, and facilitating data-driven decision-making across seed production and distribution networks.

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Mobile-based advisory platforms have become an important tool for delivering real-time information to farmers. These platforms provide recommendations on varietal selection, pest and disease management, irrigation scheduling, nutrient management, and weather forecasting. By improving access to timely information, digital advisory services help farmers make informed production decisions and optimize resource utilization.

Artificial intelligence (AI) and data analytics are increasingly being utilized for demand forecasting, inventory management, market intelligence, and production planning. Predictive analytics enables seed companies to anticipate market demand more accurately, reduce inventory costs, and improve supply chain responsiveness. Data-driven decision-making also supports the identification of emerging market opportunities and consumer preferences.

Blockchain technology is gaining attention as a potential solution for enhancing traceability and transparency within seed supply chains. By creating immutable records of seed production, processing, certification, and distribution activities, blockchain systems can improve accountability and reduce the prevalence of counterfeit seeds. Enhanced traceability also strengthens consumer confidence and facilitates compliance with regulatory standards.

E-commerce platforms are transforming traditional distribution channels by enabling direct interactions between seed suppliers and farmers. Online marketplaces provide greater product visibility, expanded market reach, and improved price transparency. Farmers benefit from access to a wider range of seed products, while companies gain opportunities to serve geographically dispersed markets more efficiently.

The emergence of agri-startups has further accelerated innovation within the seed sector. Startups are developing digital marketplaces, precision agriculture solutions, smart nursery technologies, remote sensing applications, and traceability systems that address specific challenges across horticultural value chains. These entrepreneurial ventures are contributing to increased competitiveness and modernization within the agribusiness landscape.

Despite their potential, the adoption of digital technologies remains uneven across regions and farmer categories. Limited digital literacy, inadequate internet connectivity, and affordability constraints continue to restrict technology adoption among smallholder farmers. Therefore, investments in digital infrastructure, capacity building, and inclusive innovation strategies are essential for maximizing the benefits of digital transformation.

As digital agriculture continues to evolve, the integration of emerging technologies will play an increasingly important role in strengthening seed systems, improving market efficiency, and supporting sustainable horticultural development in India.

| PPP Model | Key Features | Major Benefits |
|---|---|---|
| Contract Seed Production | Company-farmer agreements for seed multiplication | Assured buy-back, stable income |
| Licensing Agreements | Public varieties licensed to private firms | Faster commercialization |
| Seed Village Programmes | Cluster-based seed production | Local seed availability |
| FPO-led Enterprises | Collective production and marketing | Better bargaining power |
| Nursery Partnerships | Protected nursery development | Quality planting material |

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## 8. Market Analysis and Emerging Agribusiness Models

The Indian horticulture seed industry has experienced substantial growth over the past two decades, driven by rising demand for high-value crops, increasing adoption of hybrid technologies, urbanization, and changing dietary preferences. The growing commercialization of agriculture has transformed seeds from a basic production input into a strategic component of agribusiness development and value chain competitiveness.

India's seed market is estimated to be among the largest in Asia, with vegetable seeds representing one of the fastest-growing segments. Private sector participation accounts for a significant share of the horticultural seed market, particularly in hybrid vegetables where adoption rates exceed those observed in traditional cereal crops. The increasing demand for superior quality produce, climate-resilient varieties, and export-oriented cultivation has further stimulated investment in research, breeding, and seed production activities.

Several innovative agribusiness models are reshaping the horticulture seed ecosystem. Protected nursery enterprises have emerged as an important business opportunity, supplying plug-tray seedlings, grafted plants, and disease-free planting materials to commercial growers. These enterprises improve crop establishment, reduce seed wastage, and enhance production efficiency while creating employment opportunities in rural areas.

Digital seed marketplaces represent another significant innovation. Online platforms enable farmers to access a wide range of seed products, compare prices, obtain technical information, and place orders directly from suppliers. Such platforms reduce information asymmetry, improve market transparency, and strengthen linkages between producers and consumers.

Community seed enterprises and farmer-led seed businesses are also gaining importance in promoting localized seed security and strengthening rural entrepreneurship. These initiatives facilitate decentralized seed production and distribution while preserving locally adapted genetic resources. In many regions, farmer producer organizations have successfully integrated seed business operations into broader agricultural value chains, enhancing income generation and collective bargaining power.

Export-oriented seed production has emerged as a promising area of growth. Favorable agro-climatic conditions, skilled labor availability, and competitive production costs have positioned India as an attractive destination for global seed production. International demand for hybrid vegetable seeds offers substantial opportunities for expanding seed exports and strengthening India's presence in global agricultural markets.

The convergence of technological innovation, institutional support, and market expansion is creating a dynamic environment for agribusiness entrepreneurship within the seed sector. Continued investment in innovation, infrastructure, and market development will be essential for sustaining long-term growth and competitiveness.

| Year | Trend |
|---|---|
| 1990 | Low private participation |
| 2000 | Moderate growth |
| 2010 | Expansion of hybrid seeds |
| 2020+ | Digital and startup-led growth |

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## 9. Challenges and Constraints in Horticultural Seed Systems

Despite significant advancements, several challenges continue to impede the development of efficient and inclusive horticultural seed systems in India. Addressing these constraints is critical for ensuring long-term sustainability and maximizing the benefits of market-driven approaches.

One of the most significant challenges is the high cost of hybrid seeds. Although hybrid varieties offer substantial productivity advantages, their affordability remains a concern for many small and marginal farmers. Limited access to institutional credit further restricts the adoption of improved planting materials, particularly among resource-constrained households.

The proliferation of counterfeit and substandard seeds represents another major concern. Fake seeds not only reduce agricultural productivity but also undermine farmer confidence in formal seed markets. Weak enforcement mechanisms and inadequate monitoring systems often allow counterfeit products to enter supply chains, resulting in economic losses for both farmers and legitimate seed companies.

Climate change poses additional challenges to seed production and crop performance. Rising temperatures, erratic rainfall patterns, droughts, floods, and emerging pest and disease pressures affect both seed multiplication activities and field-level productivity. Developing climate-resilient varieties and strengthening adaptive capacity have therefore become strategic priorities for the seed industry.

Infrastructure deficiencies continue to constrain value chain efficiency. Inadequate storage facilities, limited cold-chain infrastructure, and poor transportation networks negatively affect seed quality and viability. These challenges are particularly pronounced in remote and underserved regions where access to markets and support services remains limited.

Regulatory bottlenecks also affect sectoral growth. Lengthy approval procedures for new varieties and hybrids can delay commercialization and discourage innovation. While regulatory oversight is essential for maintaining quality standards, excessive procedural complexity may reduce the competitiveness of the seed sector.

Furthermore, digital and informational inequalities restrict the adoption of emerging technologies among smallholder farmers. Limited access to digital tools, technical training, and market information can exacerbate existing disparities and reduce the inclusiveness of market-driven seed systems.

Addressing these challenges requires coordinated interventions involving policymakers, research institutions, private enterprises, farmer organizations, and development agencies. A holistic approach that combines technological innovation, institutional strengthening, infrastructure development, and regulatory reform is essential for building resilient and inclusive seed ecosystems.

## 10. Policy Recommendations and Conclusion

### Policy Recommendations

The sustainable development of market-driven horticultural seed systems requires a comprehensive policy framework that promotes innovation, competitiveness, inclusiveness, and environmental sustainability. Several strategic interventions can accelerate progress toward these objectives.

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First, investments in research and development should be increased to support the development of climate-resilient, disease-resistant, and market-oriented varieties. Strengthening collaboration between public research institutions and private companies can accelerate innovation and improve technology dissemination.

Second, public-private partnership frameworks should be expanded to facilitate investment, risk sharing, and knowledge exchange across the seed value chain. Supportive policies that encourage collaboration among research organizations, seed companies, farmer producer organizations, and agri-startups can enhance system efficiency and scalability.

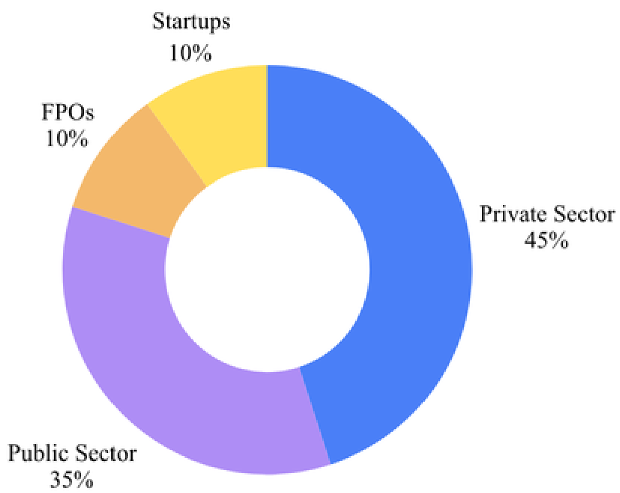
Third, regulatory processes governing varietal approval, seed certification, and quality assurance should be streamlined while maintaining rigorous standards. Simplified procedures can reduce delays, encourage innovation, and improve market responsiveness.

Fourth, investments in digital infrastructure and farmer capacity building should be prioritized. Expanding access to digital advisory services, e-commerce platforms, and traceability systems can enhance market transparency and strengthen farmer participation in modern value chains.

Fifth, targeted support should be provided to women entrepreneurs, youth-led enterprises, and farmer producer organizations engaged in seed production and marketing activities. Inclusive business models can contribute significantly to rural employment generation and economic empowerment.

Finally, strengthening anti-counterfeit measures, improving seed quality monitoring systems, and expanding storage and logistics infrastructure will be essential for maintaining farmer confidence and ensuring the integrity of seed markets.

**Stakeholder Contribution to Horticulture Seed Ecosystem**




## Conclusion

The transformation of horticultural seed systems from traditional input delivery mechanisms into integrated agribusiness ecosystems represents a significant opportunity for advancing agricultural development in India. Market-oriented seed systems supported by strong value chain linkages, technological innovation, and

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institutional collaboration can substantially improve productivity, profitability, and sustainability across the horticulture sector.

Public-private partnerships have emerged as a powerful instrument for combining scientific expertise, entrepreneurial capacity, financial investment, and market knowledge. These partnerships facilitate innovation, accelerate technology transfer, and strengthen the commercialization of improved varieties and planting materials. At the same time, digital technologies are creating new possibilities for enhancing transparency, efficiency, and market access throughout seed value chains.

Although challenges related to affordability, quality assurance, climate change, infrastructure, and regulation persist, strategic investments and policy reforms can significantly improve sector performance. A coordinated market systems approach that promotes innovation, inclusiveness, and resilience will be critical for realizing the full potential of India's horticulture seed industry.

As demand for high-quality horticultural products continues to grow domestically and internationally, strengthening seed systems will remain central to achieving food security, nutritional well-being, rural prosperity, and sustainable agribusiness development. With appropriate institutional support and stakeholder collaboration, India is well positioned to emerge as a global leader in horticultural seed production, innovation, and value chain development.

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# Integrated Management of Postharvest Diseases in Tomato Using Conventional and Advanced Techniques

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## Abstract

Tomato is a highly perishable vegetable crop that is susceptible to postharvest diseases caused mainly by fungal and bacterial pathogens. These diseases result in fruit decay, quality deterioration, reduced shelf life and significant economic losses during handling, storage, transportation and marketing. Integrated management provides a sustainable approach by combining conventional practices with advanced technologies. Conventional methods include careful harvesting, sanitation, sorting and grading, proper packaging, temperature and humidity management, refrigeration, heat treatments and the use of approved chemical or biological treatments. Advanced techniques such as hyperspectral imaging, machine learning, computer vision, biosensors and Internet of Things-based monitoring enable early disease detection and continuous assessment of storage conditions. Emerging technologies, including cold plasma, ultraviolet treatment, ozone, ultrasound, electrolysed water, edible coatings and smart packaging, may further reduce microbial growth while maintaining fruit quality. Integrating these approaches can minimise postharvest losses, extend shelf life and promote sustainable tomato supply chains

## Introduction

Tomato is one of the most important vegetable crops because of its nutritional value, wide consumption and economic importance (Biradar et al., 2026). However, tomatoes are highly perishable and may develop several diseases after harvesting. Fungal and bacterial infections can cause soft rot, mould growth, discolouration, tissue breakdown and rapid loss of market quality (Sunkad et al., 2022). These problems may occur during harvesting, handling, transportation, storage and marketing.

## Causes and Effects of Postharvest Diseases

Postharvest diseases are often associated with mechanical injuries, poor sanitation, high temperature and unsuitable storage conditions. Pathogens can enter tomato fruits through cuts, bruises and damaged tissues. Once infection begins, the disease may spread rapidly from one fruit to another. Therefore, effective disease management should not depend on a single treatment. An integrated approach that combines conventional practices with advanced technologies can provide safer, more efficient and sustainable protection (Mediga et al., 2026).

## Conventional Practices for Disease Management

Conventional management begins with careful harvesting and proper handling. Tomatoes should be harvested at the appropriate maturity stage and handled gently to avoid bruising and skin damage. Damaged, overripe and diseased fruits should be removed during sorting and grading. Clean harvesting containers, tools and packaging materials are also important because they reduce the spread of disease-causing microorganisms.

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## Importance of Proper Storage

Proper storage is another essential component of disease management. Suitable temperature and relative humidity can slow fruit ripening and reduce the growth of many pathogens. However, excessively low temperatures may cause chilling injury and reduce tomato quality. Good ventilation and clean storage facilities are therefore necessary.

Conventional approaches such as refrigeration, heat treatments, modified-atmosphere storage and approved sanitising treatments can help reduce postharvest losses. Their effectiveness depends on proper application and suitable storage conditions.

## Biological and Natural Disease-Control Methods

Biological and natural treatments are also becoming important in postharvest disease management. Beneficial microorganisms can suppress disease-causing pathogens by competing for nutrients and space or by producing natural antimicrobial compounds.

Plant extracts (Biradar et al, 2021c), bioagents (Biradar et al., 2021b) organic acids and edible coatings (Biradar et al., 2021a) may provide additional protection. Edible coatings form a thin protective layer around the tomato, reducing moisture loss and slowing quality deterioration. These approaches may reduce dependence on chemical treatments and support environmentally responsible postharvest management.

## Advanced Technologies for Early Disease Detection

Advanced technologies including multi-omics (Biradar P. and Namrata, 2024; Rao and Sunkad, 2024), genetic engineering (Biradar Pratiksha et al., 2023), genome sequencing (Biradar et al., 2023), gene editing (Patait Neha et al., 2024), are improving the early detection and control of postharvest diseases. Hyperspectral imaging can examine tomatoes at many wavelengths beyond normal human vision. It may identify small changes in moisture, pigments and tissue structure before clear symptoms become visible (Patil et al., 2026).

When combined with machine-learning algorithms, hyperspectral information can be used to classify healthy and infected fruits rapidly. Early identification allows diseased tomatoes to be separated before the infection spreads to healthy fruits (Patil et al., 2023).

## Artificial Intelligence and Smart Monitoring

Artificial intelligence and computer vision can support automated disease detection and sorting. Cameras installed on grading lines can inspect large numbers of tomatoes and identify fruits with visible defects.

Smart sensors and Internet of Things systems can continuously monitor temperature, humidity and other storage conditions. When unfavourable conditions are detected, the system can provide warnings so that corrective action can be taken quickly. These technologies can improve decision-making and reduce losses during storage and transportation.

## Emerging Non-Thermal Technologies

Emerging non-thermal technologies, including ultraviolet treatment, cold plasma, ozone-based washing,

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ultrasound and electrolysed water, are being investigated for reducing microbial populations while maintaining important quality characteristics. These methods may provide alternatives or supplements to conventional chemical treatments.

Advanced packaging technologies, including active packaging, antimicrobial packaging and smart packaging, can also help maintain tomato quality. Some smart packaging materials can indicate changes in temperature, freshness or storage conditions.

## Integrating Conventional and Advanced Approaches

The future of tomato disease management lies in combining these methods rather than replacing conventional practices completely. Good sanitation, careful handling and appropriate storage remain the foundation of postharvest disease management.

Advanced imaging, artificial intelligence, smart sensors and novel preservation technologies can add early detection, rapid decision-making and improved disease control. Combining conventional and advanced approaches can provide more reliable protection than using a single method.

## Conclusion

Integrated management of postharvest diseases in tomato combines practical knowledge with modern technology. This approach can reduce postharvest losses, improve fruit quality, extend shelf life and increase returns throughout the tomato supply chain. By adopting both conventional and advanced techniques, farmers, traders, storage operators and the food industry can contribute to a safer, more efficient and sustainable tomato production and marketing system.

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# Speed Breeding as a Tool for Rapid Generation Advancement in Crop Improvement Programs

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**Abstract**

Speed breeding (SB) is an innovative technique aimed at enhancing crop improvement by significantly shortening generation cycles, enabling multiple plant generations within a single year. This method relies on extended light exposure, controlled environmental conditions and optimized growth practices to reduce the time required for breeding major crops. The paper explores the fundamental principles of speed breeding, its application across various crop species and its potential to address global food security challenges driven by climate change.

## Introduction

For most of the field crops, the breeding of new cultivars takes several years. After crossing with selected parental lines, 4–6 generations of inbreeding are generally required to develop stable lines for evaluation of yield and yield attributing traits as well as other quality characters. This is particularly time consuming and are often limited to only 1–2 generations per year. So, need to fasten the breeding cycle for generation of new advanced cultivars holds the utmost priority here. This can be achieved by Speed Breeding (SB). In speed breeding, we optimize light, temperature and other growth factors to accelerate the breeding process. But the primary driving force which results in accelerated growth of plants is photoperiod. Prolonged photoperiod accelerates the developmental rate of plants, and the harvesting and germination of immature seed, thereby reducing generation time.

In the 1980s, John W. Finley and Todd T. Herzog from the USDA's Agricultural Research Service in Mississippi first practiced speed breeding by using artificial lighting to grow multiple wheat crops in a year. Around the same time, NASA and Utah State University worked together on a research program to grow wheat on a space station, aiming to meet astronauts' dietary needs. This led to the creation of the USU-Apogee, the first dwarf wheat variety developed through speed breeding (Ghosh *et. al.,* 2018; Hickey *et al.,* 2019). In the 1990s, as scientists at the University of Wisconsin studied the effects of LED lights on plant growth, a discovery that boosted the research and application of speed breeding in crop improvement. Inspired by NASA's space efforts, researchers at the University of Queensland introduced the term "speed breeding" in 2003 to improve wheat breeding more rapidly. To reduce generation time even further, speed breeding is now combined with technologies like double haploid (DH) methods and embryo rescue (Ahmar *et. al.,* 2020).

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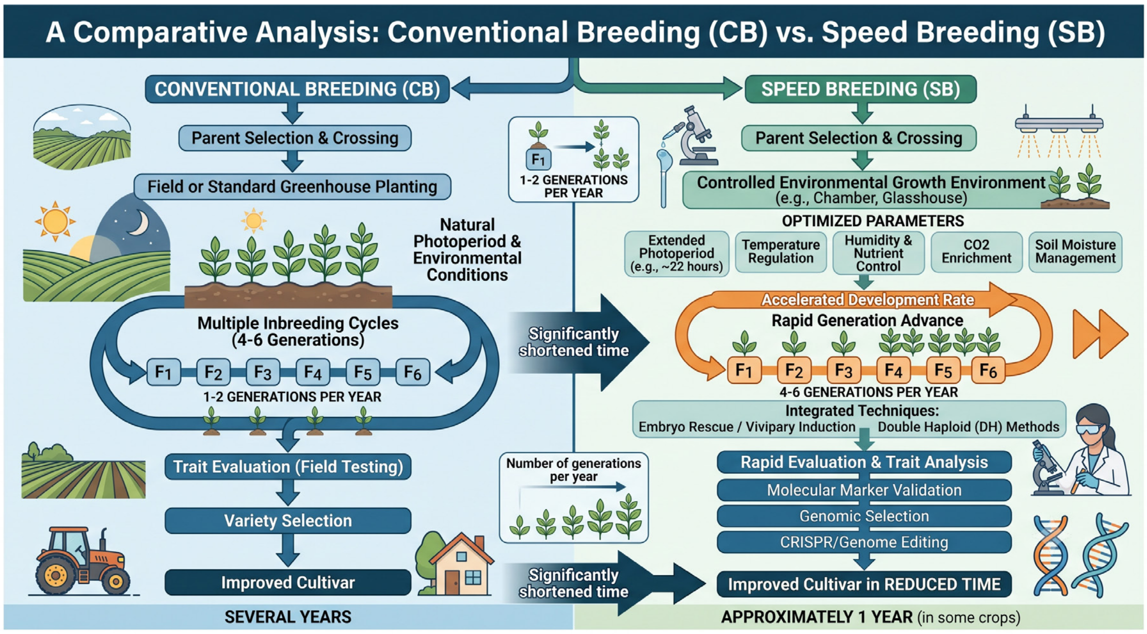
Researchers at the University of Queensland in Australia developed a speed breeding protocol to overcome the challenges posed by continuous light on plant growth, seed harvesting and germination of immature seeds. Using this technique, up to six generations per year have recently been achieved in crops like wheat (*Triticum aestivum*), durum wheat (*T. durum*), barley (*Hordeum vulgare*), chickpea (*Cicer arietinum*) and pea (*Pisum sativum*) (Ghosh *et. al.,* 2018b; Watson *et. al.,* 2018a).Similarly, for canola (Brassica napus), speed breeding has enabled the production of four generations annually, compared to just two to three generations under normal greenhouse conditions (Watson *et. al.,* 2018b; Ghosh *et. al.,* 2018a). In addition, this approach has been successfully extended to accelerate the breeding process in orphan or underutilized crops (Chiurugwi *et. al.,* 2019).




## Methods

Watson *et. al.,* (2018b) described three speed breeding methods: speed breeding 1 (controlled environmental growth chamber), speed breeding 2 (glasshouse speed breeding conditions), and speed breeding 3 (low-cost homemade growth room). A Conviron BDW chamber (Conviron, Canada) was used to create controlled growing conditions. It was set to a 22-hour photoperiod with a temperature of 22 °C during the light period and 17 °C during the 2-hour dark period. To mimic natural sunrise and sunset, both light and temperature gradually ramped up and down over 1 hour and 30 minutes. Humidity inside the chamber was maintained at 70%.

The lighting setup included a mix of white LED bars (Valoya; 6 units per 7.6 m²), far-red LED lamps (Valoya; 12 units per 7.6 m²), and ceramic metal hydrargyrum quartz iodide lamps (Valoya; 32 units per 7.6 m²). After the ramping period, the highest light intensity at bench height—where the pots were placed—was 360–380 µmol $m^{-2}$ $s^{-1}$, and at mature plant height (for example, wheat *T. aestivum cv. Paragon*), it reached 490–500 µmol $m^{-2}$ $s^{-1}$. The spectral quality of the light used is detailed in Supplementary.

A glasshouse with temperature control and fitted with high-pressure sodium vapour lamps (Philips SON-T 400 W E E40 in Sylvan High Bay housing with a glass diffuser) was used for the experiment. The setup followed a 17/22 °C temperature cycle with a 12-hour shift and a 22-hour photoperiod . During the 2-hour night period when the lamps were off, the temperature was maintained at 17 °C.

Light intensity at mature plant height, approximately 45 cm above the bench, ranged from 440–650 µmol $m^{-2}$ $s^{-1}$. Unlike some other systems, there was no ramping up or down of light or temperature. The spectral quality of the light used is provided in Supplementary.

A low-cost alternative to the Conviron BDW chamber was created using a 3 m × 3 m × 3 m room lined with insulated sandwich panels. The room was equipped with seven LB-8 LED light boxes (one per 0.65 $m^2$), and a 1.5-horsepower inverter split-system domestic air conditioner. The light spectrum is detailed in Supplementary.

The LED lights were mounted 140 cm above the bench, delivering photosynthetically active radiation (PAR) intensities of 210–260 µmol $m^{-2}$ $s^{-1}$ at bench height and 340–590 µmol $m^{-2}$ $s^{-1}$ at 50 cm above the pots. The lighting schedule started with a 12-hour photoperiod (12 hours dark) for the first 4 weeks and was later extended to an 18-hour photoperiod (6 hours dark). There was no ramping of light intensity during transitions between light and dark periods.

The air conditioner maintained the room at 21 °C when the lights were on and 18 °C during the dark period, with fluctuations within ±1 °C. The room had the capacity to hold 90 pots, each 20.3 cm in diameter and 5 L in volume. Automatic irrigation was controlled by a Hunter 10 Station Irrigation Controller, using a single solenoid per room and a 13 mm main line with individual spike drippers for each pot. Humidity was kept at ambient levels.

**Factors affecting speed breeding**

Drastic environmental changes significantly affect plant growth. Speed breeding works by accelerating photosynthesis, which depends on key factors like temperature, light duration and intensity, soil nutrients and moisture, $CO_2$ levels and plant density. Carefully controlling these elements is essential for successful speed breeding.

Different plants need different photoperiods (lengths of day and night) to flower and produce seeds. Long-day plants flower faster under extended light, while short-day plants like rice need shorter light periods, which makes developing protocols for them more challenging. Light quality and intensity (especially in the PAR range of 400–700 nm) greatly affect plant development. Far-red and blue light influence flowering and plant shape differently in various species. LED lights are commonly used in speed breeding due to their energy efficiency. Researchers have developed specific protocols for many crops, including wheat, barley, chickpea, canola, peanut, soybean, amaranth, and rice, achieving up to 4–6 generations per year. For rice, a carefully adjusted light schedule helps overcome its short-day flowering requirement. Speed breeding has also been combined with modern breeding tools to create improved varieties like the salt-tolerant rice line YNU31-2-4. Overall, speed breeding helps reduce generation time and supports faster crop improvement.

Temperature is a key factor in speed breeding, as both soil and air temperatures within critical ranges are necessary for seed germination, flowering, seed set, seed maturity and overall plant growth and development. Most crops require temperatures between 12 and 30 °C for germination, and between 25 and 30 °C for flowering, seed development and growth Humidity levels around 60–70% are generally ideal for plant growth,

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though lower humidity is preferred for crops adapted to dry conditions.

Soil moisture plays a vital role in plant growth and development, influencing processes like flowering, seed set, and maturity. Studies have shown that both drought and flooding can trigger early flowering and maturation. Gradual reduction in soil moisture after flowering has been found to speed up grain filling and maturation in crops like chickpea, wheat, canola, and barley, highlighting the importance of soil water management in speed breeding (Wanga *et. al.,* 2021; Shavrukov *et. al.,* 2017; Vadez *et. al.,* 2012; Watson *et. al.,* 2018a).

High planting density can trigger early flowering and maturity due to competition for light, which is a low-cost method effective in crops like cotton, rice and sorghum (Warnasooriya & Brutnell 2014; Wanga *et. al.,* 2021). In cassava, grafting high-flowering genotypes onto low-flowering ones can enhance flowering rates (Silva Souza *et. al.,* 2018). Proper air flow (0.3–0.5 m/s) is also essential for plant growth, as it supports gas exchange and photosynthesis, as shown in lettuce grown hydroponically (Peiro *et. al.,* 2020). Additionally, vivipary—early seed germination before dispersal—can be triggered by stress or pathogens and plays a role in plant development under speed breeding conditions (Pliszko & Górecki 2021).

Different plant species and genotypes react uniquely to carbon dioxide ($CO_2$) levels. In some cases, higher $CO_2$ concentrations can promote early flowering and accelerate the shift from vegetative to reproductive growth stages (Wanga *et. al.,* 2021).

Phytohormones and nutrients also play a key role in seed germination, flower induction, and seed formation. For example, using a mix of auxin and cytokinin resulted in 100% in vitro flowering and 90% seed set in faba bean (Mobini *et. al.,* 2015). Similarly, Yao *et. al.,* (2017) showed that culturing wheat embryos in half-strength MS medium with 4% sugar and a tenfold increase in $KH_2PO_4$ led to 100% flowering and 92% seed set in two wheat varieties. Additionally, drying and chilling techniques can break seed dormancy in immature seeds of various crops (Ghosh *et. al.,* 2018b).

**Speed Breeding Protocols for crops**

The speed breeding protocol for rice, termed Speed Flower was developed using controlled walk-in growth chambers with regulated light, temperature and humidity. Seeds from *indica* and *japonica* varieties were dormancy-broken at 40–45 °C for 48 hours before sowing in sterilized soil with farmyard manure. Optimization trials identified that a 2R > 1B light spectrum, supplemented with shade avoidance (SAR) and end-of-day far-red (EOD FR) light, combined with a 24-hour photoperiod for the first 15 days followed by 10-hour short days and 800 μmol/m²/s light intensity at 32/30 °C day/night with 65% humidity, induced early flowering and tillering. Premature seeds harvested 15 days after flowering were treated with 60–80 ppm $GA_3$ to achieve over 80% germination. This complete protocol successfully accelerated generation turnover in 198 rice genotypes from the 3K Rice Genome Project, enabling multiple generations per year (Kabade *et. al.,* 2024)

To assess speed breeding for cereal research, standard genotypes of wheat (*T. aestivum, T. durum*), barley (*H. vulgare*) and *Brachypodium distachyon* were grown under a 22-hour light/2-hour dark cycle to maintain circadian gene expression. Compared to glasshouse-grown plants (without added light/heat), speed-bred plants flowered in nearly half the time—35–39 days for wheat, 37–38 days for barley and 26 days for *B. distachyon*. Though wheat had slightly fewer seeds per spike, both wheat and barley maintained healthy spike

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numbers and seed viability. Crosses between wheat cultivars, including tetraploid and hexaploid, were also successful under these conditions (Watson *et. al.,* 2018).

In groundnut, continuous light and controlled temperature enabled inbreeding of $F_2$–$F_4$ generations within a year. In soybean, five generations per year were achieved using LED lighting, early seed harvest and a 10-hour photoperiod. For canola, factors like soil, light, temperature and irrigation were optimized and immature embryos were cultured to accelerate generation turnover. Temperatures above 33 °C were found to reduce flowering time but increase male sterility, especially in soybean (Chaudhary and Sandhu, 2024).

Speed breeding (SB) protocols have been increasingly applied to legume species, especially temperate pulses like chickpeas, lentils, faba beans and peas, as well as some warm-season legumes such as common beans, cowpeas, pigeon peas, soybean and groundnut. These crops generally show positive responses to long photoperiods due to their facultative long-day nature. Controlled environments with continuous light have significantly improved growth rates, particularly in peanuts and peas. A combination of in vitro and in vivo approaches has enabled up to eight lentil generations per year, while in vivo methods alone have proven effective for crops like peas and grass peas. Techniques like harvesting immature seeds (e.g., in pigeon pea) and using artificial light (e.g., 60W bulbs in chickpea) have enhanced flowering and germination rates. Since 2016, SB has been integrated into public breeding programs in Australia for cool-season legumes, aiding rapid cultivar development and gene-trait association studies.

Speed breeding protocols have been established for vegetable crops, with ongoing research to extend these methods to other legumes, leafy vegetables and herbs. In crops like radish, pea and tomato, standardized protocols have improved yield under continuous light. The CAB-13 gene was introgressed in tomato to enhance tolerance to continuous light, enabling cultivation under 24-hour photoperiods. Potato breeding has benefited from continuous long-day light in controlled environments, speeding up flowering and seed maturity. Pepper also responds to continuous light with early flowering and fruiting. Onion, a biennial crop requiring 10–12 years for varietal development, can have its cycle shortened using dormancy-breaking treatments, reducing bulb maturation time to 46–80 days instead of 5–6 months. Overall, these protocols significantly reduce generation times and enhance breeding efficiency across several vegetable crops.

**Applications**

One of its primary benefits is the ability to accelerate the breeding cycle, enabling up to six generations per year in photoperiod-insensitive crops like wheat and barley and two to three generations in photoperiod-sensitive crops such as rice or soybean. This rapid generation turnover shortens the time needed to develop new, improved crop varieties with desirable traits such as disease resistance, drought tolerance or higher yield. Speed breeding also supports the process of genomic selection by allowing faster advancement of breeding lines through multiple generations, which helps breeders validate and apply genetic markers more efficiently. Moreover, SB is an ideal method for developing large breeding populations in a short period of time. These populations are crucial for mapping important traits and identifying quantitative trait loci (QTLs), which are essential for genetic improvement. SB also plays a critical role in modern biotechnology, especially in transgenic and CRISPR-based genome editing programs. By speeding up the life cycle of plants, it enables faster testing, integration and propagation of edited genes or transgenes. In addition to genetic advancements, speed breeding can also be used to study key physiological traits such as flowering time, photosynthesis efficiency,

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stress responses and nutrient uptake under controlled environments. This allows researchers to better understand plant development and responses under various environmental conditions. Overall, speed breeding serves as a powerful and flexible tool that enhances both traditional and modern breeding strategies, making it a cornerstone in the effort to develop climate-resilient, high-yielding and nutritionally enhanced crop varieties in less time.

## Conclusion

Speed breeding (SB) is a revolutionary approach that accelerates crop improvement by significantly reducing generation time through optimized environmental conditions such as extended photoperiods, temperature regulation, controlled humidity and nutrient management. Originally initiated in wheat and enhanced through space research, SB has now expanded to a wide range of cereals, legumes, oilseeds and vegetables. It enables 4–6 generations per year in crops like wheat, rice, chickpea, soybean and tomato, using advanced facilities or cost-effective chambers. SB protocols have been effectively integrated with modern technologies such as embryo rescue and double haploidy, supporting rapid cultivar development and gene-trait studies. Furthermore, it offers great potential in breeding underutilized crops and adapting varieties to climate change. While challenges remain for short-day and biennial crops, SB continues to transform breeding programs globally by enhancing selection efficiency, reducing time and costs and ultimately boosting food security through the faster development of high-yielding, stress-resilient cultivars.

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# Holistic Pest and Disease Management in Watermelon Cultivation

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**Abstract**

Watermelon (Citrullus lanatus) is a high-value cucurbit crop cultivated widely for its nutritional, economic, and commercial importance. However, its productivity is often constrained by a wide range of insect pests and diseases that attack the crop at different growth stages. Continuous and indiscriminate use of chemical pesticides has resulted in problems such as resistance development, pest resurgence, environmental pollution, and pesticide residues in produce. Integrated Pest Management (IPM) and Integrated Disease Management (IDM) offer sustainable and eco-friendly approaches by combining cultural, mechanical, biological, and need-based chemical control methods. These integrated strategies help reduce crop losses, improve fruit quality, and ensure safe production while maintaining ecological balance.

**Introduction**

Watermelon is an important summer fruit crop grown extensively in tropical and subtropical regions. Its cultivation is highly profitable, but the crop is vulnerable to several insect pests and diseases that significantly reduce yield and market quality. Major insect pests such as fruit flies, aphids, whiteflies, thrips, and mites cause direct damage to plants and also act as vectors for viral diseases. In addition, diseases like damping off, mildews, wilt, and viral infections further aggravate losses.

Traditional pest and disease control practices mainly depend on chemical pesticides. However, excessive reliance on chemicals is no longer sustainable due to rising costs, environmental hazards, and health risks. Therefore, ICAR recommends integrated approaches like IPM and IDM, which emphasize preventive measures, biological control, and minimal use of chemicals. These strategies help maintain pest and disease populations below economic threshold levels while ensuring long-term sustainability.

**Major Insect Pests of Watermelon :**

**Red Pumpkin Beetle (** *Aulacophora foveicollis )*

This is one of the most destructive pests during the early growth stage. Adult beetles feed on cotyledons and tender leaves, creating irregular holes, while larvae damage roots and underground plant parts. Severe infestation leads to wilting, poor plant establishment, and sometimes complete plant death.

**Fruit Fly (** *Bactrocera cucurbitae )*

Fruit fly is a major pest during the fruiting stage. Females lay eggs inside fruits, and the maggots feed internally. Affected fruits show puncture marks, oozing of fluid, rotting, and premature dropping. Infested fruits become

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unmarketable due to deformation and decay.

**Thrips (** *Thrips tabaci* **)**

Thrips attack plants throughout growth stages. Feeding causes silvery patches on leaves, curling, and drying. Severe infestation results in stunted growth, distorted fruits, and flower drop, ultimately reducing yield.

**Aphids (** *Myzus persicae, Aphis gossypii* **)**

Aphids are sap-sucking insects that weaken plants by feeding on plant sap. They also secrete honeydew, which promotes sooty mould growth. Additionally, aphids transmit viral diseases, leading to severe yield losses.

**Whitefly (** *Bemisia tabaci* **)**

Whiteflies damage plants by sucking sap and transmitting viral diseases. Symptoms include yellowing of leaves, curling, reduced vigour, and formation of black sooty mould due to honeydew secretion.

**Spider Mite (** *Tetranychus urticae* **)**

Mites cause yellow speckling on leaves, which later turns into bronzing or scorching. Fine webbing is seen on leaves, and severe infestation leads to drying of plants and reduced fruit quality.

**Integrated Pest Management (IPM) Strategies**

**Cultural Practices**

Practice crop rotation with non-host crops

Use healthy and certified seeds

Follow timely sowing to avoid peak pest incidence

Maintain proper spacing and balanced nutrition

Keep fields clean and free from weeds

Avoid excessive nitrogen fertilization

**Mechanical and Physical Methods**

Install yellow sticky traps for monitoring sucking pests

Use pheromone traps to control fruit flies

Handpick and destroy visible pests

Remove and destroy infested fruits and plant parts

**Biological Control**

Conserve beneficial insects such as ladybird beetles and lacewings

Encourage natural predators and parasitoids

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Use neem-based products and botanicals

**Chemical Control**

Apply insecticides only when pest population exceeds threshold levels

Use selective and recommended chemicals

Rotate insecticides to prevent resistant

**Major Diseases of Watermelon.**

**Fusarium Wilt :** This disease affects plants at all growth stages. Seedlings may collapse, while older plants show gradual wilting, especially during the daytime. Eventually, plants die, and fruits, if formed, are small and poor in quality.

**Anthracnose :** This disease causes reddish-brown spots on leaves, which enlarge and give a ragged appearance. Severe infection leads to drying of leaves and exposure of vines.

**Powdery Mildew :** Characterized by white powdery growth on leaves, this disease spreads rapidly and causes drying and brittleness of leaves, leading to poor fruit quality.

**Downy Mildew :** Symptoms appear as yellow spots on leaves with greyish growth on the underside. Leaves eventually dry and die, especially under humid conditions.

**Integrated Disease Management (IDM) Practices**

Use resistant or tolerant varieties

Select healthy and disease-free seeds

Treat seeds to eliminate pathogens

Follow crop rotation with non-cucurbit crops

Maintain proper spacing and aeration

Avoid overlapping plantings

Remove and destroy infected plant parts

Eliminate weed hosts and volunteer plants

Prevent spread through contaminated tools and water

Manage irrigation to avoid excess moisture

Apply fungicides only when necessary

Monitor crop regularly for early detection

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## Conclusion

Integrated Pest and Disease Management is essential for sustainable watermelon production. By combining cultural, biological, mechanical, and chemical methods, farmers can effectively manage pests and diseases while reducing dependence on pesticides. These practices not only improve yield and fruit quality but also protect the environment and ensure safe food production. Regular monitoring, early intervention, and adoption of integrated strategies are key to successful watermelon cultivation.

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# Crispr Driven Advances In Seed Research

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**ABSTRACT**

CRISPR-Cas9 is a powerful genome-editing technology that has transformed seed science by enabling precise modification of genes controlling important seed traits. It has been successfully used to regulate seed dormancy, develop male-sterile lines for hybrid seed production, and improve the nutritional quality of oilseed crops. Compared with conventional breeding, CRISPR offers a faster and more accurate approach to crop improvement. With continued advancements, this technology has great potential to support sustainable agriculture by developing high-yielding, climate-resilient, and nutritious crop varieties.

**Key words:** CRISPR Cas 9, Genome editing, Seed dormancy, Hybrid seed production, Male sterility, Crop improvement.

## INTRODUCTION

Seed science forms the backbone of global agriculture and food security. The quality, viability, and performance of seeds determine crop yields and agricultural resilience. Traditional breeding methods have successfully improved seed traits for decades. However, these conventional approaches are often slow and lack precision.

The emergence of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) technology has revolutionized plant biotechnology. CRISPR-based gene editing allows scientists to make highly precise, targeted changes directly within the plant genome. Conventional gene editing tools (ZFN and TALEN) require complex, time-consuming protein engineering for every new target sequence. In contrast, CRISPR is cheaper, faster, and much easier to design because it only requires changing a short, programmable guide RNA. CRISPR-Cas 9 technology has emerged as a powerful genome-editing tool that enables precise and efficient modification of plant genes. Its ability to improve important agronomic traits has opened new opportunities in crop improvement, plant breeding, and seed science.

## CRISPR Cas 9 TECHNOLOGY

CRISPR-Cas9 is a genome editing technology used to change parts of the genome by removing, adding, or altering sections of DNA. It uses a pre-designed RNA sequence to guide the Cas9 enzyme to the location where the genome needs to be altered. The Cas9 enzyme then cleaves the DNA strands, and the cell's natural repair mechanism joins the two ends together by removing, adding, or replacing certain sections.

## HOW DOES CRISPR-Cas 9 WORK

CRISPR/Cas9 gene editing begins with the design of a guide RNA (gRNA) that matches the target DNA sequence. The guide RNA and Cas9 protein are then delivered into the plant cell. Inside the cell, the gRNA

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directs the Cas9 enzyme to the target site by recognizing a short DNA sequence called the protospacer adjacent motif (PAM). Once the correct target is identified, the guide RNA binds to the DNA, and the Cas9 enzyme cuts both DNA strands. The cell immediately activates its natural DNA repair system to repair the break. If no repair template is provided, the DNA is repaired through non-homologous end joining (NHEJ), which often introduces small mutations that can disable the target gene (gene knockout). If a repair template is supplied, the cell repairs the DNA through homology-directed repair (HDR), allowing precise insertion or replacement of the desired DNA sequence (gene knock-in). This precise editing process has made CRISPR/Cas9 a powerful tool for crop improvement and seed science (Hirakawa *et al*., 2020; Rafiq 2024)

## SEED DORMANCY BREAKING

Dormancy prevents precocious germination and helps seeds survive unfavourable conditions. However, excessive dormancy can delay and reduce the uniformity of germination, leading to poor crop establishment. Therefore, regulating seed dormancy is important for improving crop performance. This could be achieved by CRISPR Cas 9 technology.

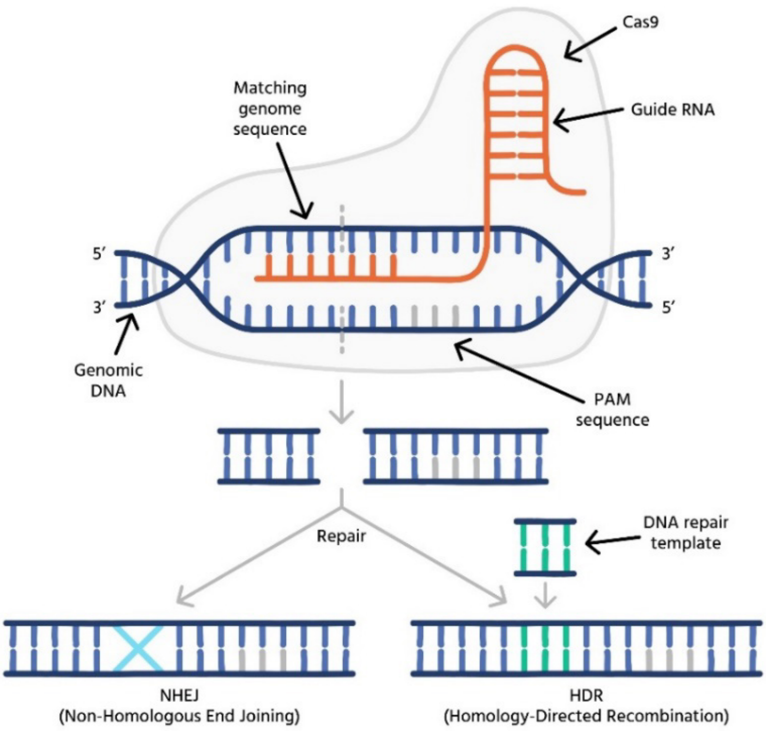


**Fig. 1 CRISPR genome editing**

Jung *et al*., 2019 reported that OsVP1 gene in rice plays a key role in regulating seed maturation, dormancy, and the abscisic acid (ABA) signalling pathway. Its activation promotes seed dormancy. Using CRISPR technology, the OsVP1 gene can be silenced to reduce dormancy, resulting in increased α-amylase activity, earlier seed germination, and stable inheritance of the desired trait.

Wheat is highly susceptible to pre-harvest sprouting, which reduces grain and seed quality. The TaQsd1 gene plays an important role in regulating seed dormancy. Abe *et al.* (2019) used CRISPR/Cas9 to create a loss-of-function mutation in all three copies of the TaQsd1 gene in hexaploid wheat. The resulting triple-recessive mutant exhibited a significantly longer seed dormancy period than the wild type, which could help reduce pre-harvest sprouting. The study also produced a transgene-free mutant with stable inheritance,

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demonstrating the potential of CRISPR for improving seed dormancy in wheat.

**MALE STERILE LINES FOR HYBRID SEED PRODUCTION**

| CROP | TARGET GENE | MALE STERILITY TYPE | REFERENCE |
|---|---|---|---|
| Wheat (*Triticum aestivum*) | NP1 | Complete male sterility | Li *et al.,* 2020 |
| Rice (*Oryza sativa)* | TMS5 | Thermosensitive genic male sterility (TGMS) | Zhou *et al.,* 2016 |
| Rice (*Oryza sativa)* | CSA (Carbon Starved Anther) | Photoperiod sensitive genic male sterility (PGMS) | Li *et al., 2016* |
| Maize (*Zea mays*) | MS8 | Nuclear male sterility | Chen *et al.,* 2018 |
| Maize (*Zea mays*) | MS26 (ZmMS26) | Nuclear male sterility | Qi *et al.,* 2020 |
| Soybean (*Glycine max)* | GmAMS1 | Nuclear male sterility | Chen *et al.,* 2021 |
| Tomato *(Solanum lycopersicum)* | SIMS10 | Nuclear male sterility | Jung *et al.,* 2020 |
| Tomato *(Solanum lycopersicum)* | SIAMS | Nuclear male sterility | Bao *et al*., 2022 |
| | | | |

**Table 1. CRISPR/Cas9-mediated development of male-sterile lines in different crop species for hybrid seed production**

CRISPR/Cas9 has emerged as an effective tool for generating male-sterile lines required for hybrid seed production. Its successful application in several crops highlights its potential to simplify hybrid breeding, enhance seed production efficiency, and contribute to sustainable agricultural development.

## ENHANCEMENT OF FATTY ACID COMPOSITION

*Camelina sativa* is an important oilseed crop valued for the production of edible oils and biofuels. However, its oil contains a high proportion of polyunsaturated fatty acids (PUFAs), which reduce its oxidative stability and shelf life. The FAD2 gene plays a key role in fatty acid biosynthesis by converting oleic acid into linoleic acid. Jiang *et al*. (2017) used the CRISPR/Cas9 genome-editing system to silence the FAD2 gene and improve the fatty acid composition of camelina oil. This resulted in an increase in oleic acid content from 16% to 50%, while linoleic acid and linolenic acid contents decreased from 16% to 4% and from 35% to 10%, respectively. These changes enhanced the nutritional quality and industrial value of camelina oil.

The SEED FATTY ACID REDUCER (SFAR) genes in soybean act as negative regulators of seed oil accumulation by promoting lipid breakdown during seed development. Liao *et al.* (2023) used CRISPR/Cas9 to disrupt multiple SFAR genes in soybean. The edited plants showed a significant increase in seed oil content without affecting protein content, demonstrating the potential of CRISPR technology to improve oil yield and seed quality in soybean.

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## CONCLUSION

CRISPR-based genome editing has transformed seed science by enabling precise modification of genes that control important seed traits. It has been used to improve seed size, dormancy, germination, nutritional quality, and stress tolerance in many crops. Compared with conventional breeding, CRISPR is faster and more precise, making crop improvement more efficient. It also helps researchers understand the role of genes in seed development. New techniques such as base editing and prime editing have further improved the accuracy of genome editing. Despite challenges such as off-target effects and regulatory concerns, CRISPR has great potential to develop high-yielding, climate-resilient, and nutrient-rich crop varieties, supporting the future of sustainable agriculture.

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