



AgriScope

Monthly e-Magazine on Interdisciplinary Science

Visit us at: www.agriscope.in

Email us at: agri4scope@gmail.com



**Volume-02
Issue-04
April-2026**

EDITORIAL BOARD

Editor-in-Chief

Dr. Kajal Kumar Biswas (IARI)

Managing Editor

Dr. Karishma Baidya (Department of Agricultural Extension)

Editorial Board Members

Dr. Kaushik Pradhan (UBKV, West Bengal)

Dr. Tanmay Samajdar (KVK, West Bengal)

Dr. Md Mokidul Islam (KVK, Meghalaya)

Dr. Aniruddha Roy (ICAR, Meghalaya)

Dr Yengkhom Linthoingambi Devi (CAU, Imphal)

Dr H G Kencharaddi (CCS Meghalaya)

Dr. Toran Lal Sahu (MGUVV, Raipur)

Dr. Manoj Kanti Debnath (UBKV, West Bengal)

Dr. Tarun Kumar Das (KVK, Meghalaya)

Dr. Govindaraj Kamalam Dinesh (CAU, Manipur)

Dr. Sabita Mondal (UBKV, West Bengal)

Index

Article ID	Article Title	Page
24001	Fruit Cracking: A Physiological Disorder Affecting Yield And Marketability	01-04
24002	Beyond the Cold Chain: Leveraging AI-Driven Digital Twins and Smart Technologies to Minimize Horticultural Carbon Footprints	05-10
24003	CRISPR-Driven Innovations in Horticulture: Bridging Molecular Genetics, Post-Harvest Physiology and Insect Ecology	11-16
24004	From Waste to Wealth: Turning Agricultural Residues into Rural Income Opportunities	17-21
24005	Hyperspectral Imaging (HSI) for Internal Quality Assessment of Fruits: Detection of Hidden Browning and Sugar Content (°Brix)	22-27
24006	Linseed: A Versatile Crop Integrating Nutrition, Oil Production and Natural Fibre for Sustainable Agriculture	28-33
24007	Harnessing Rootstock Potential For Sustainable Fruit Production In Warm Regions	34-38
24008	National Turmeric Board: A Landmark Shift in India's Agricultural Policy and Export Strategy	39-43

FRUIT CRACKING: A PHYSIOLOGICAL DISORDER AFFECTING YIELD AND MARKETABILITY

Anjali^{1*} Sejal² Nivedita³

¹M.Sc. Student, Department of Fruit Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan,
Himachal Pradesh, India

²M.Sc. Student, Department of Food Science and technology, COHF, Neri, Dr. YSPUHF, Nauni,
Solan, Himachal Pradesh, India

Corresponding author email- anjalidhima930@gmail.com

Article ID: 24001

INTRODUCTION

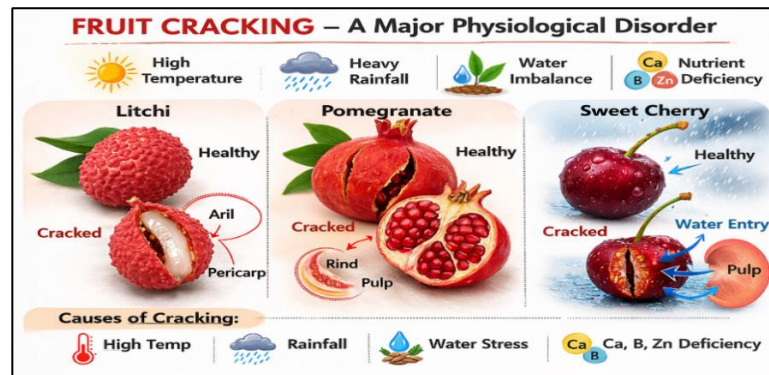
India ranks second in global fruit production after China and is often called the fruit basket of the world due to its diverse climate that supports the cultivation of numerous fruit crops. However, significant losses occur because of physiological disorders, among which fruit cracking is a major problem. Fruit cracking is a pre-harvest physiological disorder characterized by rupture or splitting of the fruit skin or cuticle, sometimes extending deep into the pulp (Rangare et al., 2023). The average loss due to this disorder ranges from 50–85%, greatly reducing fruit quality and making the produce unmarketable, leading to substantial economic losses for growers. Fruit cracking commonly occurs in several horticultural crops such as cherry, plum, apricot, apple, litchi, pomegranate, citrus, banana, avocado, grape, persimmon, peach, tomato and pistachio (Khadivi-Khub., 2009). Therefore, understanding the causes of fruit cracking and adopting suitable management strategies are essential for minimizing losses and improving fruit quality.

Fruit cracking in Litchi: High temperature (above 38 °C), low humidity (below 60%) and low soil moisture conditions during fruit development promote this disorder in Litchi. In Litchi, it is associated with the “Ball- skin bladder effect”, where the pericarp fails to expand uniformly with aril growth.

Fruit cracking in pomegranate: There are many reasons that causes fruit cracking in pomegranate: hot dry winds, heavy rainfall following a dry spell, difference in day and night temperature, nutritional deficiency especially boron, calcium, zinc and potash (Saei et al., 2014) are directly associated with fruit cracking in pomegranate.

Fruit cracking in Cherry: Two major causes of fruit cracking in Sweet cherries are as follows:

- **Water relation within the tree:** Trees growing in soils saturated from precipitation or over irrigation take up excess water. As the fruit matures, sugar concentration rise, establishing a large osmotic potential and leads to cracking.
- **Free standing rainwater on ripening fruit:** The rise in sugar concentration in ripening fruit sets an osmotic gradient across the surface. Prolonged contact between cuticle and water results in water entering the fruit.



PHYSIOLOGICAL MECHANISM OF FRUIT CRACKING

Cracking due to water imbalance:

Fruit cracking often occurs when abundant water becomes available after a prolonged dry period. During drought conditions, xylem and phloem tissues become hardened and lose their capacity to expand. When water supply suddenly increases, the internal tissues resume rapid growth while the rigid vascular tissues fail to expand accordingly. This difference in growth rate results in rupture of the fruit peel.

Cracking due to environmental stress:

Environmental conditions such as high temperature and low humidity during summer cause the fruit peel to become hard and inelastic. When heavy rainfall occurs during the rainy season, the internal tissues expand rapidly due to increased water uptake. Since the peel cannot expand at the same rate, the fruit skin ruptures, leading to cracking.

MITIGATION STRATEGIES

1. Irrigation Management :

Drought stress followed by a sudden surge of water can increase fruit cracking. (Wang et al., 2021). Light but frequent irrigation that maintain a congenial microclimate within and around

the plant has been found to minimize cracking in Litchi .To prevent cracking, maintaining a consistent water supply through drip irrigation is recommended.

2. Nutrient Management:

Deficiencies in calcium, boron, and phosphorus are strongly associated with increased cracking. Calcium strengthens cell walls by stabilizing pectin in the middle lamella, reducing the likelihood of cracking. Boron is responsible for increasing cell elasticity and prevents breakdown of vegetative tissues.

3. Plant growth regulators

Plant Growth Regulators (PGRs) play a crucial role in controlling fruit cracking by influencing fruit development. Application of NAA enhances fruit set and improves peel elasticity, thereby reduces cracking in citrus fruits .Similarly, GA₃ application delays rind senescence and decreases cracking incidence in *Eureka* lemon. Ethylene, which accelerates ripening and softening, is also linked with cracking susceptibility.

4. Bagging and Mulching

Bagging is a physical protection technique, it reduces the incidence of fruit cracking by altering the microenvironment for fruit development. Mulching, either plastic or organic mulch along with three irrigations, was effective in controlling fruit cracking as it reduces water stress.

5. Tolerant cultivars

Tolerant cultivars should be selected while establishing new orchard. Bedana, Bombai, Elaichi, Kasba and Piazzi showed low amount of fruit cracking in litchi. The thickness of the pericarp is reported to impart resistance to cracking in most of the cultivars.

6. Anti- transpirants

Anti-transpirants are chemical compounds that reduce the rate of transpiration from plant leaves and help plants tolerate stress (El Khawaga, 2013). They decrease stomatal opening and increase leaf resistance to water vapor diffusion without significantly affecting carbon dioxide uptake. This helps reduce transpiration, maintain fruit skin elasticity, and minimize fruit cracking.

CONCLUSION

Fruit cracking is a major pre-harvest physiological disorder that occurs due to the combined effects of environmental stresses, irregular water availability, nutrient imbalance, hormonal disturbances and genetic susceptibility of cultivars. Sudden fluctuations in soil moisture, high temperature with low atmospheric humidity, and weak elasticity of the fruit peel increase internal

pressure inside the fruit, which ultimately causes the fruit surface to rupture. In addition, physiological factors such as water imbalance and environmental stress, further increase the susceptibility to cracking. Effective control of this disorder requires an integrated management approach rather than a single practice. Proper irrigation scheduling, balanced nutrient management, foliar application of calcium and boron, mulching, and adoption of cracking-tolerant cultivars can significantly reduce fruit cracking and improve fruit quality and market value.

References

1. Blanco V, Blaya-Ros PJ, Torres-Sánchez R and Domingo R. 2022. Irrigation and crop load management lessen rain-induced cherry cracking. *Plants*. 11(23):3249. <https://doi.org/10.3390/plants11233249>
2. El-Khawaga AS. 2007. Reduction in fruit cracking in Manfaluty pomegranate following foliar application with paclobutrazol and zinc sulphate. *Journal of Applied Sciences Research*. 3(9):837–840.
3. Kaur R, Kaur N, Bajya M and Bajaya T. 2022. Physiological and biochemical mechanisms of fruit cracking: A review. *Indian Journal of Agricultural Sciences*. 92(5):547–553. <https://doi.org/10.56093/ijas.v92i5.124620>
4. Khadivi-Khub A. 2009. Physiological and genetic factors influencing fruit cracking. *Acta Physiologiae Plantarum*. 31(4):633–647. <https://doi.org/10.1007/s11738-009-0278-7>
5. Rangare NR, Lal N, Kuldeep D and Bhooriya MS. 2023. Fruit cracking, its causes and management (Review). *Scientist*. <https://doi.org/10.5281/zenodo.7332732>
6. SaeiAhagh H, Sharifani MM, Seifi E, Mohseni A and Akbarpour V. 2015. How fruit traits influence cracking of pomegranate (*Punica granatum* L.). *Acta Horticulturae*. 1099:815–818. <https://doi.org/10.17660/ActaHortic.2015.1099.103>
7. Santos HG, Silva RR, Oliveira ACS and Ferreira MS. 2023. Genetic and molecular aspects of fruit cracking tolerance: Insights from watermelon rind hardness and jujube cuticular wax formation for breeding strategies. *Frontiers in Plant Science*. 14:1234567. <https://doi.org/10.3389/fpls.2023.1234567>
8. Zhang C, Wang L, Chen X and Shen Y. 2017. Role of cell wall-degrading enzymes in fruit softening and cracking during ripening. *Scientia Horticulturae*. 225:437–444. <https://doi.org/10.1016/j.scienta.2017.07.036>

Beyond the Cold Chain: Leveraging AI-Driven Digital Twins and Smart Technologies to Minimize Horticultural Carbon Footprints

Riya Verma^{*1}, Sejal², Nivedita³ and Anjali⁴

¹M.Sc. Student, Department of Food Science and Technology, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

²M.Sc. Student, Department of Food Science and Technology, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

³M.Sc. Student, Department of Fruit Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

⁴M.Sc. Student, Department of Fruit Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

Corresponding author email - vriya5787@gmail.com

Article ID: 24002

Introduction

The horticulture sector plays a vital role in global food systems, yet it remains highly dependent on energy-intensive infrastructure, particularly cold chain systems used for storage and transportation. Refrigeration, climate-controlled warehousing, and temperature-regulated logistics are essential for maintaining the quality and shelf life of fruits, vegetables, and ornamental crops. However, these systems contribute substantially to greenhouse gas (GHG) emissions due to high electricity demand and refrigerant leakage. As climate change intensifies and sustainability regulations become stricter, horticulture must transition beyond traditional cold chain management toward more intelligent, energy-efficient systems. Artificial Intelligence (AI), Internet of Things (IoT), and Digital Twin (DT) technologies are emerging as transformative solutions within climate-smart agriculture. A digital twin creates a continuously updated virtual model of a physical agricultural system, enabling real-time monitoring, simulation, and predictive optimization. These technologies facilitate data-driven decision-making that reduces resource waste, enhances productivity, and lowers carbon emissions across the horticultural value chain (Slob & Hurst, 2022; Gund et al., 2025).

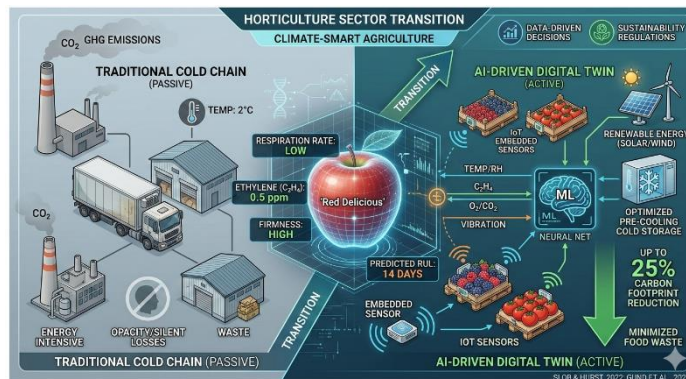


Fig.1 Climate smart agriculture

Digital Twins and Smart Technologies in Horticulture

A Digital Twin is not merely a simulation model but a dynamic, data-integrated virtual representation of a real-world system. It continuously receives information from IoT sensors embedded within the physical environment such as temperature probes, humidity sensors, soil moisture detectors, and CO₂ monitors. This bidirectional communication allows operators to test scenarios digitally before implementing changes in real systems. For example, a greenhouse manager can simulate adjustments in ventilation strategies to assess potential energy savings and crop growth outcomes without risking production losses. Such capabilities make digital twins powerful tools for operational optimization and sustainability improvement (Slob & Hurst, 2022). The integration of AI algorithms enhances the functionality of digital twins by enabling predictive analytics and machine learning based optimization. AI systems can analyze large volumes of historical and real-time environmental data to forecast crop growth patterns, disease outbreaks, and resource demands. According to Gund et al. (2025), the rapid expansion of digital twin research in agriculture reflects growing recognition of its potential to improve efficiency and environmental performance. In greenhouse horticulture specifically, advanced environmental control systems powered by digital twins have demonstrated the ability to reduce unnecessary heating and lighting while maintaining optimal crop conditions. These systems adapt dynamically to weather changes, plant developmental stages, and energy price fluctuations, resulting in measurable sustainability benefits (Van Mourik et al., 2022).

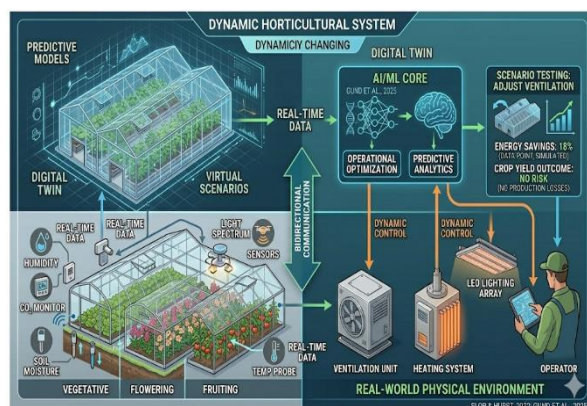


Fig.2 Dynamic horticulture system

Carbon Footprint Reduction Through Precision Climate Control

Greenhouses require continuous regulation of microclimatic conditions to ensure optimal crop growth. Traditionally, heating, cooling, and lighting systems operate based on fixed schedules or manual adjustments, often leading to overuse of energy. AI-driven digital twins change this paradigm by continuously analyzing environmental data and adjusting systems in real time. For instance, during periods of sufficient natural sunlight, artificial lighting can be reduced automatically. Similarly, predictive models can anticipate temperature drops and activate heating systems only when necessary, preventing energy oversupply. Studies indicate that such intelligent environmental control strategies significantly lower energy consumption while preserving crop yield and quality (Van Mourik et al., 2022; Slob & Hurst, 2022). By optimizing climate control operations, digital twins directly reduce electricity consumption and associated carbon emissions.

Optimized Irrigation and Nutrient Management

Water and fertilizer management represent major sources of emissions in horticulture. Excessive irrigation not only wastes water but also increases energy use for pumping and distribution. Over-application of nitrogen fertilizers contributes to nitrous oxide emissions, a potent greenhouse gas. Digital twins equipped with AI-based predictive models can assess plant water stress levels and nutrient uptake requirements in real time. By analyzing soil moisture data, evapotranspiration rates, and crop growth stages, these systems determine precise irrigation schedules tailored to plant needs. Elhariri et al. (2025) demonstrated that smart greenhouse systems integrating digital twins can significantly reduce water use without compromising productivity. Similarly, nutrient delivery systems integrated with digital twins can optimize fertigation practices by adjusting nutrient concentrations based on plant growth predictions. This precision reduces

fertilizer waste and lowers emissions associated with fertilizer production and soil nitrogen transformation processes (Gund et al., 2025). As a result, both direct and indirect carbon emissions are minimized.

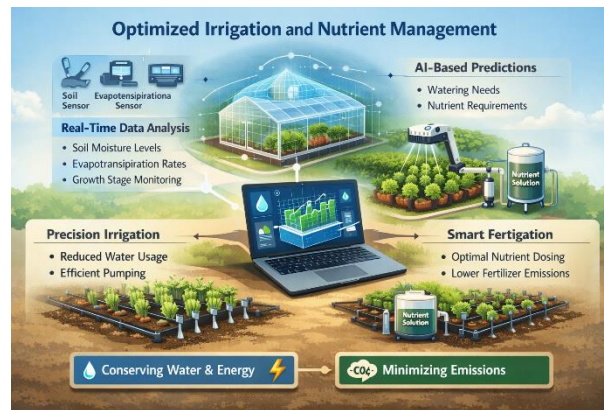


Fig.2 optimized irrigation and nutrient

Post-Harvest and Supply Chain Optimization

While production efficiency is crucial, a significant portion of horticultural emissions occurs during post-harvest storage and transportation. Cold chain systems are energy-intensive, and inefficiencies often lead to spoilage, requiring replacement production that further increases emissions. Digital twins can model entire supply chains, from packing facilities to distribution centers and retail outlets. By simulating various transport routes, storage temperatures, and delivery schedules, stakeholders can identify configurations that minimize energy use and reduce spoilage risks. Verdouw et al. (2022) highlight that digital twin enabled supply chain optimization improves logistics efficiency and reduces lifecycle emissions. Additionally, predictive analytics can forecast product shelf life based on real-time environmental exposure data. This capability allows distributors to prioritize shipments and reduce food waste, indirectly lowering the carbon footprint associated with lost produce.

Predictive Maintenance and Equipment Efficiency

Horticultural operations depend heavily on equipment such as HVAC systems, irrigation pumps, and automated conveyors. Equipment inefficiencies or unexpected breakdowns can increase energy consumption and disrupt production processes. AI-integrated digital twins monitor equipment performance continuously, analyzing parameters such as energy draw, vibration patterns, and operating temperatures. Predictive maintenance models detect anomalies and anticipate potential failures before they occur. This proactive approach prevents energy waste,

extends equipment lifespan, and reduces the need for carbon-intensive manufacturing of replacement components (Gund et al., 2025). Over time, these operational efficiencies contribute significantly to overall carbon footprint reduction.

Lifecycle Carbon Considerations

Despite their environmental benefits, digital technologies themselves carry embodied carbon costs. The manufacturing of sensors, servers, and computing infrastructure, along with data center energy consumption, contributes to emissions. Therefore, evaluating the net sustainability impact of digital twin deployment requires comprehensive lifecycle assessment. Li et al. (2024) emphasize that while digital agriculture infrastructure has an initial carbon footprint, long-term operational efficiencies generally offset these emissions, especially in large-scale horticultural systems. The key lies in ensuring that digital systems are powered by renewable energy sources and optimized for energy-efficient data processing.

Challenges and Future Perspectives

The widespread adoption of digital twin technology in horticulture faces several challenges. High initial investment costs can limit accessibility for small-scale growers. Furthermore, integrating heterogeneous data sources into unified platforms requires standardized protocols and robust cybersecurity frameworks. Limited technical expertise in rural regions may also slow implementation. However, future developments are promising. Integration with renewable energy systems such as solar-powered greenhouses can further reduce carbon intensity. Blockchain technologies may enhance supply chain transparency and carbon traceability, strengthening sustainability verification mechanisms (Tiwari, 2025). As research and technological maturity advance, digital twin ecosystems are expected to become central components of climate-resilient horticultural systems.

Conclusion

Moving beyond traditional cold chain optimization, AI-driven digital twins and smart technologies provide a comprehensive strategy for minimizing horticultural carbon footprints. Through precision climate control, optimized irrigation and nutrient management, supply chain simulation, and predictive maintenance, these systems enhance operational efficiency while reducing emissions across the value chain.

Although digital infrastructure entails embodied emissions, lifecycle assessments indicate that long-term sustainability gains outweigh initial environmental costs. With continued innovation

and supportive policies, digital twin-enabled horticulture can play a pivotal role in advancing low-carbon, climate-resilient agricultural production.

References

1. Elhariri, E., et al. (2025). Digital twin implementation for smart greenhouse environmental control. *Alexandria Engineering Journal*.
2. Gund, R., et al. (2025). Bibliometric review of digital twin technology in agriculture. *Agriculture*.
3. Li, X., et al. (2024). Estimating the carbon footprint of digital agriculture deployment. *arXiv preprint arXiv:2409.17617*.
4. Slob, N., & Hurst, W. (2022). Digital twins and Industry 4.0 technologies for agricultural greenhouses. *Smart Cities*, 5(3), 1144–1165.
5. Tiwari, S. (2025). *Blockchain and Digital Twin Applications in Smart Agriculture*. Routledge.
6. Van Mourik, S., et al. (2022). Digital twins in greenhouse horticulture: A review. *Computers and Electronics in Agriculture*, 200, 107207.
7. Verdouw, C., et al. (2022). Transforming agrifood production systems and supply chains with digital twins. *npj Science of Food*, 6, 45.

CRISPR-Driven Innovations in Horticulture: Bridging Molecular Genetics, Post-Harvest Physiology and Insect Ecology

Arti Devi^{1*}, Sejal Thakur², Sejal³, Vanshika² and Shreya⁴

¹M.Sc. Student, Department of Basic Sciences, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

²M.Sc. Student, Department of Entomology, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

³M.Sc. Student, Department of Food Science and Technology, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

⁴M.Sc. Student, Department of Vegetable Sciences, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

^{1*}Corresponding author email - artidevi2842004@gmail.com

Article ID: 24003

1. Introduction

Horticultural crops are key sources of vitamins and micronutrients, yet **20–40% of fruits and vegetables are lost post-harvest** in developing countries due to physiological deterioration, microbial spoilage, mechanical damage and insect pests (FAO). Processes such as respiration, ethylene production and oxidative stress accelerate ripening in climacteric fruits like tomato, banana and mango, while pests further increase losses by promoting infections

(Savary et al., 2019). Conventional breeding for delayed ripening and pest resistance is slow and transgenic crops like *Solanum lycopersicum* **Flavr Savr** faced public concerns. **CRISPR-Cas**

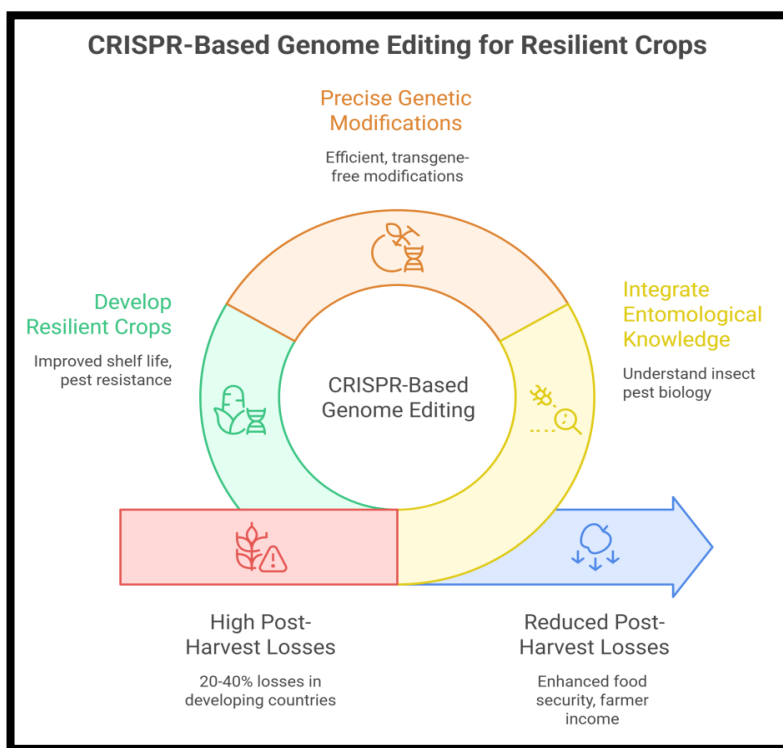


Figure 1: CRISPR- Based Genome Editing for Resilient Crops

genome editing offers a precise approach to improve shelf life and insect resistance in horticultural crops (Jaganathan et al., 2018).

2. CRISPR-Cas Genome Editing

CRISPR, derived from bacterial immune systems, uses **Cas9** guided by sgRNA to create targeted DNA double-strand breaks. These are repaired by **NHEJ**, causing insertions/deletions or **HDR**, enabling precise genome modification (Bortesi & Fischer, 2015).

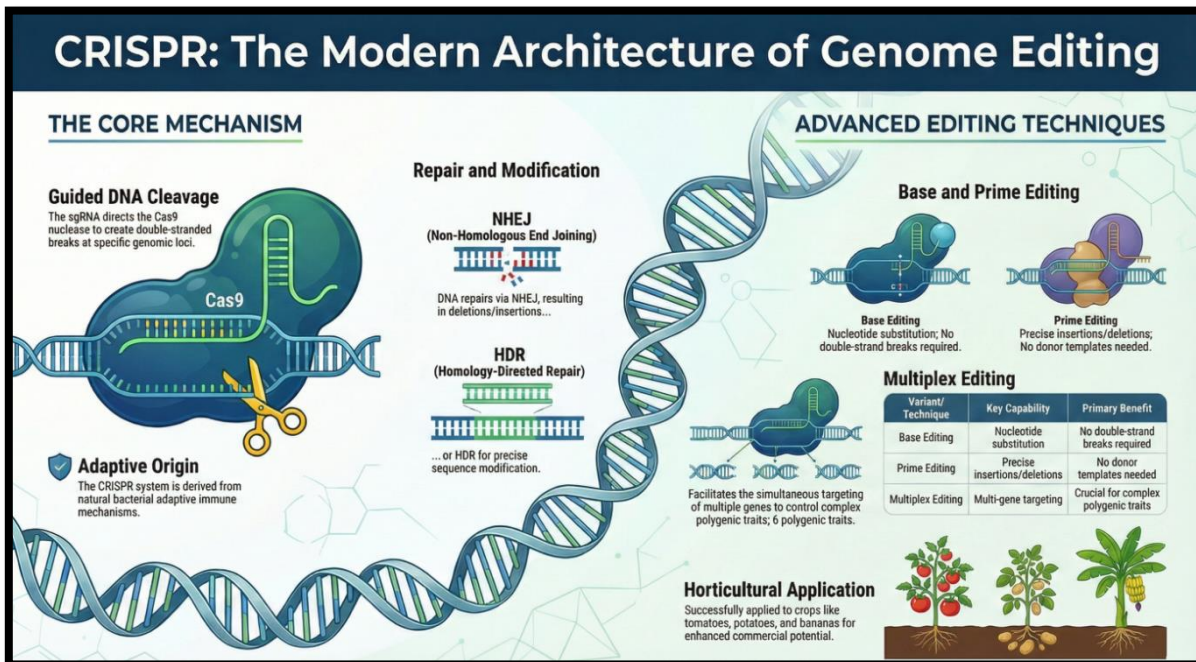


Figure 2: CRISPR-Cas Genome Editing

The most widely used CRISPR system is **SpCas9** from *Streptococcus pyogenes*, though variants like **Cas12a (Cpf1)** and **Cas13** have expanded editing capabilities.

- **Base Editing:** for single nucleotide changes (Komor et al. 2016).
- **Prime Editing:** for precise insertions, deletions and substitutions (Anzalone et al. 2019).
- **Multiplex Editing:** to target multiple genes simultaneously (Zhang et al. 2020).

3. Entomological Perspectives in Crop Improvement

3.1 Insect-Induced Pre and Post-Harvest Losses

Insect pests such as *Helicoverpa armigera*, aphids, thrips, whiteflies and *Sitophilus* spp. cause major losses in horticultural crops and increase fungal infections. Climate change further intensifies pest pressure (Deutsch et al., 2018), making stronger plant resistance essential.

3.2 Molecular Basis of Plant- Insect Interactions

Plants resist herbivorous insects through **structural barriers**, **defence signalling pathways** (JA, SA, ethylene) and **defensive metabolites and proteins**. The **jasmonic acid pathway** is central to this defence and CRISPR editing of its regulatory genes can enhance resistance without introducing foreign DNA (Howe & Jander, 2008).

4. CRISPR Applications in Insect Resistance

4.1 Editing Susceptibility (S) Genes

Certain plant susceptibility genes facilitate insect feeding or pathogen entry. Editing genes involved in cell wall loosening or nutrient transport can limit pest access to nutrients. For example, CRISPR-mediated mutation of **SWEET** sugar transporter genes enhances resistance to pathogens (Chen et al., 2019).

4.2 Enhancement of Defensive Compounds

CRISPR can enhance insect resistance by upregulating genes involved in insecticidal metabolite production. Editing terpene synthase genes may increase volatile compounds that repel herbivores or attract natural enemies, strengthening plant–insect–natural enemy interactions and supporting integrated pest management (IPM).

4.3 Gene Editing in Insect Populations

CRISPR can modify insect genomes to suppress pests through gene drives or fertility gene editing (Esvelt et al., 2014). However, potential ecological risks require careful regulation.

5. CRISPR in Post-Harvest Quality Improvement

5.1 Modification of Cell Wall Degradation

Fruit softening is driven by enzymes such as **polygalacturonase (PG)**, **pectate lyase (PL)** and **expansins**. Editing **PG genes** can produce firmer fruits with longer storage life and reduced susceptibility to insect damage and microbial infection (Uluşik et al., 2016).

5.2 Oxidative Stress and Senescence

Accumulation of **reactive oxygen species (ROS)** accelerates senescence. Editing antioxidant enzyme regulators can enhance stress tolerance and extend post-harvest life by reducing storage damage.

5.3 Case Example: Tomato as a Model Crop

Tomato (*Solanum lycopersicum*) is a key model for CRISPR-based shelf-life improvement. Editing ripening regulators such as **RIN** and **NOR** enables controlled ripening without affecting flavor (Zhang et al., 2020).

6. Integration of Entomology and Post-Harvest Biology

Integrating **insect resistance** with **delayed ripening** offers dual protection by reducing pest damage, pathogen entry and post-harvest spoilage, while slower ripening lowers metabolic activity and pest attraction during storage. This approach combines **molecular genetics, insect physiology, post-harvest biochemistry and ecological pest management**. Such integration aligns with sustainable agriculture goals by reducing pesticide reliance and minimizing food waste.

7. Advantages of CRISPR-Based Integration

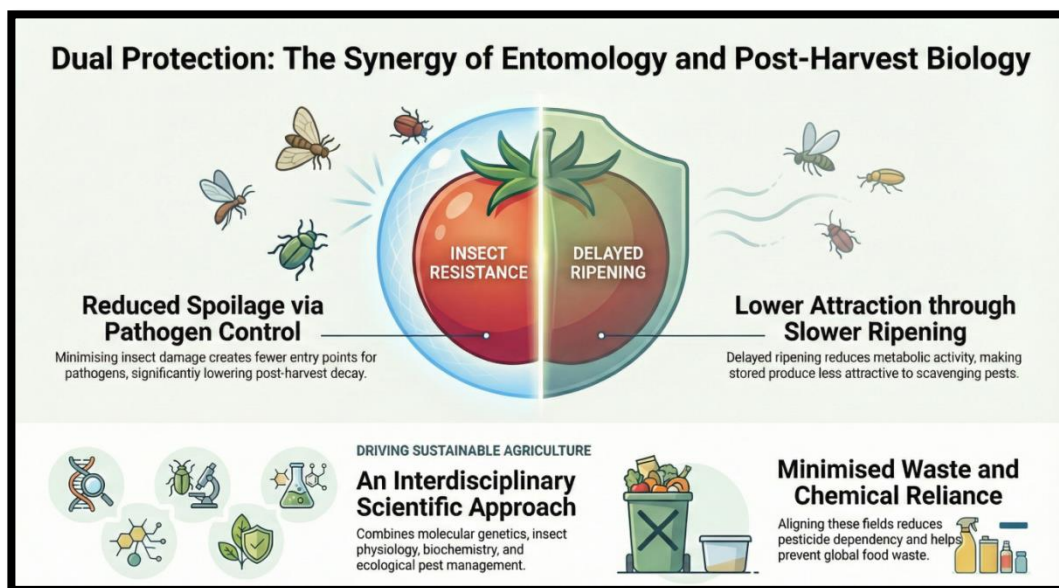


Figure 3: Interdisciplinary approach

- Reduced chemical pesticide usage
- Lower post-harvest losses
- Environmentally sustainable pest management
- Improved farmer profitability
- Enhanced nutritional and market value

Compared with conventional breeding, CRISPR significantly reduces time required for cultivar development (Jaganathan et al. 2018).

8. Challenges and Ethical Considerations

Despite its potential, CRISPR faces challenges including **off-target mutations, polygenic complexity of insect resistance, ecological concerns (especially gene drives), varying global regulations and public acceptance**. Therefore, transparent risk assessment and stakeholder engagement are essential for responsible deployment.

9. Future Prospects

Future research should focus on:

- Integration with genomics, transcriptomics, proteomics and metabolomics.
- Precision editing for improved tritrophic interactions.
- Climate-resilient pest-resistant cultivars.
- CRISPR-based epigenome editing.
- Sustainable insect population management.

The convergence of genome editing and applied entomology is poised to transform horticultural crop protection and post-harvest management.

10. Conclusion

CRISPR-based genome editing represents a transformative technology in horticulture. By integrating post-harvest biological insights with entomological innovations, it is possible to develop crops that resist insect attack while maintaining extended shelf life. This dual strategy reduces chemical inputs, minimizes food losses and promotes sustainable agricultural systems. Continued interdisciplinary research, ethical governance and public engagement will determine the success of CRISPR-driven innovations in global horticulture.

References

1. Anzalone AV, Randolph PB, Davis JR, Sousa AA, Koblan LW, Levy JM and Liu DR. 2019. Search- and- replace genome editing without double-strand breaks or donor DNA. *Nature* 576(7785): 149-157.
2. Bortesi L and Fischer R. 2015. The CRISPR/ Cas9 system for plant genome editing and beyond. *Biotechnology advances* 33(1): 41-52.
3. Deutsch CA, Tewksbury JJ, Tigchelaar M, Battisti DS, Merrill SC, Huey RB and Naylor RL. 2018. Increase in crop losses to insect pests in a warming climate. *Science* 361(6405): 916-919.
4. Esvelt KM, Smidler AL, Catteruccia F and Church GM. 2014. Concerning RNA-guided gene drives for the alteration of wild populations. *elife* 3: e03401.
5. Howe GA and Jander G. 2008. Plant immunity to insect herbivores. *Annual Review of Plant Biology* 59: 41–66.
6. Jaganathan D, Ramasamy K, Sellamuthu G, Jayabalan S and Venkataraman G. 2018. CRISPR for crop improvement: an update review. *Frontiers in plant science* 9: 985.

7. Komor AC, Kim YB, Packer MS, Zuris JA and Liu DR. 2016. Programmable editing of a target base in genomic DNA without double-stranded DNA cleavage. *Nature* 533(7603): 420-424.
8. Savary S, Willocquet L, Pethybridge SJ, Esker P, McRoberts N and Nelson A. 2019. The global burden of pathogens and pests on major food crops. *Nature ecology & evolution* 3(3): 430-439.
9. Uluisik S, Chapman NH, Smith R, Poole M, Adams G, Gillis RB and Seymour GB. 2016. Genetic improvement of tomato by targeted control of fruit softening. *Nature biotechnology* 34(9): 950-952.
10. Zhang Y, Massel K, Godwin ID and Gao C. 2018. Applications and potential of genome editing in crop improvement. *Genome biology* 19(1): 210.

From Waste to Wealth: Turning Agricultural Residues into Rural Income Opportunities

Abhay Thakur^{1*} and Anjali Devi¹

¹M.Sc. Student, Department of Social Sciences, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

*¹Corresponding author email - abhayysp@gmail.com

Article ID: 24004

Introduction

Agricultural development in India produces not only food but also enormous quantities of residual biomass. It is estimated that 350–500 million tonnes of agricultural residues are generated annually (Government of India, 2026; Reddy et al., 2025). These include crop residues such as straw and husk, horticultural waste such as fruit pomace and livestock manure.

A significant proportion of these residues is still burned in open fields, especially in northern India, contributing to severe air pollution and nutrient loss (Rossi & Srail, 2024). Burning destroys soil organic matter and releases greenhouse gases, negatively impacting long-term agricultural sustainability (Government of India, 2026).

At the same time, rural communities face issues of low income and limited livelihood diversification. Converting agricultural waste into value-added products offers a practical solution by integrating economic and environmental goals (Singh et al., 2021). The “waste to wealth” approach emphasizes transforming residues into useful products such as compost, energy and food, thereby supporting a circular economy in agriculture (Reddy et al., 2025).

Types of Agricultural Residues

Agricultural residues can be broadly classified into the following categories:

1. Crop Residues

Crop residues include straw, stalks and husks left after harvesting crops like rice, wheat, and maize. India generates approximately 250–300 million tonnes of crop residues annually (Government of India, 2026). While some residues are used as fodder, a large portion remains unutilized or is burned.

2. Horticultural Waste

Horticultural waste includes fruit and vegetable residues such as peels, pomace and pruning materials. For example, apple processing generates significant amounts of pomace, which can be converted into value-added products (Dubey et al., 2025).

3. Livestock Waste

Livestock waste, including dung and urine, is widely available in rural areas. It can be used for biogas production and organic manure, contributing to sustainable farming systems (Singh et al., 2021).

Type of Waste	Examples	Potential Uses
Crop residues	Rice straw, wheat straw	Compost, biochar, biogas, briquettes
Horticultural waste	Fruit peels, pomace	Compost, enzymes, biofuels
Livestock waste	Cow dung, poultry litter	Biogas, organic fertilizer
Agro-processing waste	Rice husk, oilseed cake	Energy, feed, fertilizers

Table 1: Types of Agricultural Waste and Their Uses

Technologies for Waste Utilization

1. Mushroom Cultivation

Mushroom cultivation utilizes agricultural residues such as straw as a substrate. It requires low investment and provides quick returns, making it suitable for small farmers (Srivastava et al., 2025). Studies have shown that mushroom cultivation can generate substantial income within short production cycles (Singh et al., 2024).

2. Composting and Vermicomposting

Composting converts organic waste into nutrient-rich manure. Vermicomposting enhances this process using earthworms and yields higher economic returns (Singh et al., 2021). It also improves soil fertility and reduces dependence on chemical fertilizers.

3. Biogas Production

Biogas is produced through anaerobic digestion of organic waste. It serves as a clean energy source while producing nutrient-rich slurry as a by-product (Ministry of Jal Shakti, 2026). Government initiatives such as GOBARdhan promote biogas production at the rural level.

4. Briquetting and Pelletization

Agricultural residues can be compressed into briquettes and pellets, which serve as alternative fuels. These products are used in industries and power plants, providing additional income to farmers (Kanagaraj et al., 2017).

5. Biochar Production

Biochar is produced through pyrolysis and improves soil fertility while sequestering carbon. It contributes to climate change mitigation and sustainable agriculture (Reddy et al., 2025).

Economic Potential and Livelihood Opportunities

The economic benefits of agricultural waste utilization are significant. Studies indicate that vermicomposting provides higher returns compared to traditional composting and biogas production (Singh et al., 2021).

Table 2: Economic Returns from Waste-to-Wealth Technologies

Enterprise	Input	Output	Net Return
Vermicomposting	1 tonne dung	Compost	₹2,225
Biogas	1 tonne dung	Gas + slurry	₹537
Mushroom cultivation	Straw	Mushrooms	₹208 per unit
Briquettes	Biomass	Fuel	₹1,229

Source: Singh et al. (2021); Kanagaraj et al. (2017)

These enterprises also generate employment opportunities for rural youth and women, contributing to livelihood diversification (Srivastava et al., 2025).

Case Studies

Punjab

Punjab has implemented innovative strategies to manage crop residues by converting them into bioenergy and industrial products. Organized supply chains have enabled farmers to sell residues instead of burning them (Rossi & Srail, 2024).

Himachal Pradesh

In Himachal Pradesh, horticultural waste such as apple pomace is being utilized for composting and enzyme production, demonstrating region-specific waste utilization (Dubey et al., 2025).

Biogas Initiatives

Community-based biogas plants under the GOBARdhan scheme are converting livestock waste into energy and fertilizer, supporting rural development (Ministry of Jal Shakti, 2026).

Challenges

Despite its potential, several challenges hinder the adoption of waste-to-wealth practices:

- Limited access to technology and machinery
- Weak market linkages and price uncertainty
- Lack of awareness among farmers
- Financial constraints and high initial investment
- Institutional and policy coordination gaps

Addressing these challenges requires integrated efforts involving policy, research, and extension services (Reddy et al., 2025).

Policy Support and Government Initiatives

The Government of India has introduced several initiatives to promote agricultural waste utilization:

- Crop Residue Management Scheme (Government of India, 2026)
- GOBARdhan Scheme (Ministry of Jal Shakti, 2026)
- National Biofuel Policy (Government of India, 2018)

These initiatives provide financial assistance, infrastructure, and training to farmers, encouraging sustainable practices.

Conclusion

Agricultural residues represent a valuable resource for rural development. Converting waste into wealth offers economic, environmental, and social benefits. Technologies such as mushroom cultivation, composting, and bioenergy production can significantly enhance farmer income while reducing environmental degradation (Srivastava et al., 2025; Singh et al., 2021).

However, scaling these solutions requires improved infrastructure, stronger market linkages, and effective policy implementation. A coordinated approach involving government, private sector, and farmers is essential to realize the full potential of agricultural waste utilization.

References (APA 7th Edition)

1. Dubey, A., Gaur, H. S., Manzoor, U., Singh, S., Singh, P. K., Devi, C. A., & Ahmed, B. (2025). Bioconversion of horticultural waste into value-added products: A review. *Indian Journal of Horticulture*, 82(4), 375–394.
2. Government of India. (2018). *National policy on biofuels*.
3. Government of India. (2026). Circular economy in agriculture: Waste to wealth. Press Information Bureau.
4. Kanagaraj, N., Desiraju, K., & Kumar, K. P. (2017). Cost and returns of briquette production in Tamil Nadu, India. *International Journal of Current Microbiology and Applied Sciences*, 6(7), 1238–1242.
5. Ministry of Jal Shakti. (2026). Fund allocated in GOBARDHAN scheme. Press Information Bureau.
6. Reddy, A. S., Kasa, V. P., Samal, B., Dubey, B. K., Yadav, V., & Pandey, D. S. (2025). Sustainable agricultural waste management in India: Innovations, challenges, and future perspectives. *Biomass and Bioenergy*, 202, 108261.
7. Rossi, L. A., & Srai, J. S. (2024). Configuring circular by-product supply networks through public–private partnerships. *Journal of Cleaner Production*, 441, 143484.
8. Singh, K., Sharma, S., & Kumar, P. (2024). Exploring the potential of oyster mushroom cultivation as remunerative agri-enterprise in Punjab. *Indian Journal of Ecology*, 51(6), 1341–1344.
9. Singh, R., Tiwari, R., Chandras, & Dutt, T. (2021). Augmentation of farmers' income in India through sustainable waste management techniques. *Waste Management Research*, 39(6), 849–859.
10. Srivastava, M., Kumar, S., Gupta, R. P., & Rai, D. (2025). Mushroom cultivation in India: Employment generation and turning agricultural waste into nutritional wealth. *Journal of Extension Systems*, 41(2), 1–8.

Hyperspectral Imaging (HSI) for Internal Quality Assessment of Fruits: Detection of Hidden Browning and Sugar Content (°Brix)

Sejal^{1*}, Riya Verma² and Anjali³

¹M.Sc. Student, Department of Food Science and Technology, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

²M.Sc. Student, Department of Food Science and Technology, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

³M.Sc. Student, Department of Fruit Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

Corresponding author email- sejalsharma062@gmail.com

Article ID: 24005

1. Introduction

Consumer demand for high-quality fruits has increased the need for rapid, non-destructive methods to assess internal quality. Conventional measurements of SSC (°Brix), firmness, and internal browning are destructive and labour-intensive. Hyperspectral imaging (HSI) offers a non-destructive alternative by combining imaging and spectroscopy to capture both spatial and spectral information from fruit tissues (ElMasry et al., 2012; Gowen et al., 2007). It records reflectance across the visible and near-infrared regions (400–1700 nm), producing a three-dimensional hypercube where each pixel contains a spectrum. This enables early detection of biochemical and structural changes such as sugar accumulation, moisture variation, and tissue browning before visible symptoms appear (Zhu et al., 2017; Wan et al., 2025).

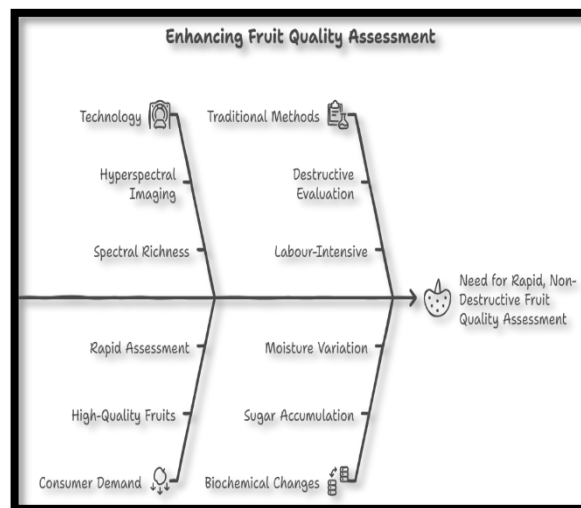


Figure 4: Enhancing Fruit Quality Assessment

2. Principles of Hyperspectral Imaging in Fruit Quality Evaluation

Hyperspectral imaging (HSI) detects internal fruit changes based on molecular absorption in the near-infrared (NIR) region, mainly from O–H, C–H, and N–H bonds associated with water, sugars, and organic acids, enabling correlations between spectral reflectance and internal composition (Cen & He, 2007; Wang et al., 2025). Internal browning alters light absorption and scattering due to phenolic oxidation, tissue degradation, and moisture redistribution, producing detectable spectral changes before visible symptoms appear (Gowen et al., 2007; Wan et al., 2025). A typical HSI system includes an illumination source, spectrograph with camera, scanning mechanism, and chemometric data analysis software, with push-broom systems widely used for fruit grading due to their high spectral resolution (El Masry et al., 2012).

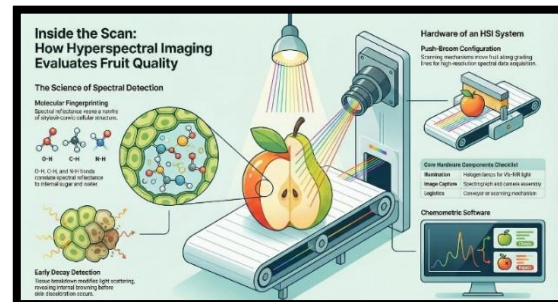


Figure 5: Hyperspectral Imaging in Fruit Quality Evaluation

Table 1. Key Internal Quality Parameters Detected by HSI

Quality Parameter	Spectral Region (nm)	Detection Basis	Typical Modeling Method	Application
Soluble Solids Content (SSC, °Brix)	900-1700	O-H and C-H bond absorption	PLSR, ANN, CNN	Sweetness grading
Internal Browning	400-1000 & NIR	Phenolic oxidation & structural change	SVM, PLS-DA, CNN	Early defect detection
Moisture Content	970, 1450	Water absorption bands	PLSR	Drying monitoring
Firmness	Vis-NIR combined	Tissue structural variation	PLSR, ANN	Ripeness prediction
Acidity (TA)	NIR region	Organic acid spectral features	PLSR	Maturity evaluation

3. Detection of Internal Browning Using HSI

Internal browning in fruits such as apple, pear, and mango often results from chilling injury, storage disorders, or mechanical damage. These changes alter phenolic content and cellular structure, leading to shifts in spectral reflectance in both visible and NIR regions (Gowen et al. 2007). Hyperspectral imaging enables pixel-level classification of healthy and browned tissues using multivariate algorithms such as Partial Least Squares Discriminant Analysis (PLS-DA) and Support Vector Machines (SVM) (El Masry et al. 2012). Studies reviewed by Wan et al. (2025) highlight HSI's ability to detect subsurface browning and quality deterioration before visible discoloration appears, demonstrating its effectiveness for early internal defect detection.

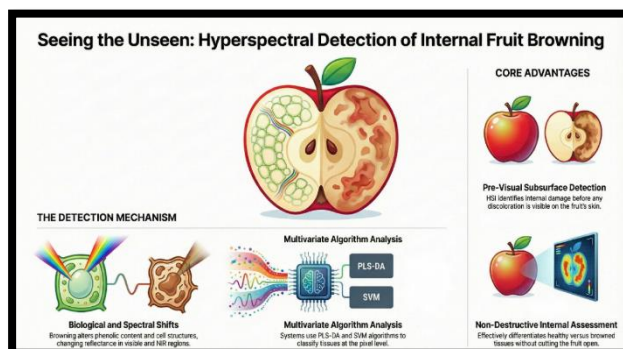


Figure 6: Detection of Internal Browning Using HSI

4. Prediction of Sugar Content (°Brix) Using HIS

Soluble solids content (SSC, °Brix) indicates fruit sweetness and maturity, but conventional refractometer measurement is destructive. Hyperspectral imaging (HSI) offers a rapid, non-destructive alternative by using spectral signatures related to sugar absorption. Sugars exhibit characteristic absorption in the NIR region (900–1700 nm) due to O–H and C–H bond vibrations, enabling SSC prediction using models such as Partial Least Squares Regression (PLSR) (Cen & He, 2007; Wang et al., 2025). Studies have shown accurate SSC prediction in fruits like kiwifruit using wavelength selection and machine learning approaches (Zhu et al., 2017; Wang et al., 2025).

5. Chemometric and Machine Learning Approaches

Hyperspectral imaging (HSI) generates high-dimensional spectral data that require chemometric and machine learning methods to analyze fruit quality attributes such as soluble solids content (SSC) and internal browning. Preprocessing techniques including Savitzky–Golay smoothing, Standard Normal Variate (SNV), Multiplicative Scatter Correction (MSC), and derivative transformations reduce noise and scattering effects (Cen & He, 2007). Models such as Partial Least Squares Regression (PLSR) predict SSC and moisture, while Support Vector Machines (SVM) classify defects. Advanced approaches like Artificial Neural Networks (ANN)

and Convolutional Neural Networks (CNNs) can automatically learn spectral–spatial features, improving prediction accuracy and real-time HSI applications (Wan et al., 2025).

6. Applications Across Different Fruits

Hyperspectral imaging (HSI) is widely used for non-destructive assessment of fruit quality attributes such as soluble solids content (SSC), firmness, moisture, maturity, and internal browning. In apples, Vis–NIR wavelengths (400–1700 nm) are used to predict SSC, firmness, and acidity and detect internal disorders (Gowen et al., 2007). HSI has also been applied to kiwifruit for predicting SSC, firmness, and pH, and to persimmon for monitoring moisture and soluble solids during drying (Chen et al., 2022). Similar applications are reported for mango, peach, grape, citrus, and strawberry for evaluating ripeness, sugar content, and internal defects. Studies indicate that with appropriate wavelength selection and modeling, HSI can be effectively applied across various fruit species (El Masry et al., 2012; Wan et al., 2025).

7. Advantages of HSI in Internal Quality Assessment

Hyperspectral imaging (HSI) enables rapid, non-destructive evaluation of internal fruit quality, allowing spectral data to be captured within seconds for high-throughput analysis (Gowen et al., 2007). It can detect early biochemical and structural changes such as internal browning or chilling injury before visible symptoms appear (Wang et al., 2025). A single scan can also predict multiple quality attributes including soluble solids content, moisture, firmness, acidity, and pigments using chemometric and machine learning models. Additionally, HSI provides spatial mapping of fruit tissues and can be integrated with automated grading systems for real-time sorting in postharvest management.

Table 2. Advantages and Limitations of HSI in Fruit Quality Assessment

Advantages	Explanation	Limitations	Explanation
Non-destructive	Fruit remains intact	High equipment cost	Expensive cameras and lighting
Early detection	Identifies defects before visible symptoms	Large data volume	Requires strong computational resources
Multi-parameter prediction	Simultaneous SSC, moisture, defects	Calibration variability	Models may not transfer across varieties
Spatial mapping	Pixel-level defect visualization	Environmental sensitivity	Affected by lighting and positioning

Automation compatible	Suitable for grading lines	Standardization issues	Lack of universal protocols
-----------------------	----------------------------	------------------------	-----------------------------

8. Challenges and Limitations

Despite its potential for non-destructive fruit quality assessment, hyperspectral imaging (HSI) faces several challenges for large-scale commercial adoption. The high cost of equipment and specialized installation limits its use mainly to research institutions and high-value fruit industries (El Masry et al. 2012). HSI also produces large datasets that require advanced computational resources and efficient algorithms for real-time processing (Gowen et al. 2007). In addition, calibration models may not perform consistently across different varieties or environmental conditions, requiring calibration transfer methods (Wan et al. 2025). Sensitivity to illumination, sample positioning, and fruit surface variability can also affect spectral accuracy, while the complexity of hyperspectral data analysis and lack of standardized industrial protocols further limit widespread implementation.

9. Future Perspectives

Hyperspectral imaging (HSI) has strong potential for detecting internal browning and predicting soluble solids content (SSC), but wider commercial use requires further development. Integration with deep learning models such as CNNs can improve prediction accuracy and enable real-time detection (Wan et al., 2025; Wang et al., 2025). Current research also focuses on portable, low-cost sensors and multispectral systems targeting key wavelengths, as well as data fusion with thermal, X-ray, or fluorescence imaging to enhance defect detection. With advances in sensors and computing, HSI is expected to support smart grading systems for real-time fruit quality monitoring and traceability (Cen and He, 2007; El Masry et al., 2012; Wang et al., 2025).

Table 3. Future Development Directions

Research Area	Expected Advancement	Impact on Industry
Deep Learning Integration	Real-time spectral-spatial modeling	Improved accuracy and speed
Portable Sensors	Compact multispectral devices	Reduced cost and field usability
Multimodal Fusion	Integration with thermal/X-ray	Higher defect detection reliability
Smart Grading Systems	AI + IoT-enabled sorting	Precision supply chain management

10. Conclusion

Hyperspectral imaging has demonstrated significant capability in detecting hidden internal browning and predicting sugar content (°Brix) in fruits before external symptoms appear. By combining spectral physics with chemometric modeling, HSI enables rapid, non-destructive internal quality assessment. Continued advances in machine learning and sensor miniaturization will further enhance its applicability in postharvest technology and precision agriculture.

References

1. Cen H. and He Y. 2007. Theory and application of near infrared reflectance spectroscopy in determination of food quality. *Trends in Food Science & Technology* 18:72-83.
2. Chen X, Jiao Y, Liu B, Chao W, Duan X and Yue T. 2022. Using hyperspectral imaging technology for assessing internal quality parameters of persimmon fruits during the drying process. *Food chemistry* 386:132774.
3. El Masry G, Kamruzzaman M, Sun DW and Allen P. 2012. Principles and applications of hyperspectral imaging in quality evaluation of agro-food products: A review. *Critical Reviews in Food Science and Nutrition* 52:999-1023.
4. Gowen AA, O'Donnell CP, Cullen PJ, Downey G, Frias JM. 2007. Hyperspectral imaging – an emerging process analytical tool for food quality and safety control. *Trends in Food Science & Technology* 18:590-598.
5. Wan G, He J, Meng X, Liu G, Zhang J, Ma F and Wu D. 2025. Hyperspectral imaging technology for non-destructive identification of quality deterioration in fruits and vegetables: A review. *Critical reviews in food science and nutrition* 65(32):7923-7952.
6. Wang S, Liu Q, Jia W, Lin Y, Bi L, Chen D and Lv C. 2025. Application of Hyperspectral Imaging Technology in Non-destructive Testing of Core Chemical Components of Fruits. *Journal of Agricultural and Food Chemistry* 73(25):15480-15490.
7. Zhu H, Chu B, Fan Y, Tao X, Yin W and He Y. 2017. Hyperspectral imaging for predicting the internal quality of kiwifruits based on variable selection algorithms and chemometric models. *Scientific Reports* 7(1):7845.

Linseed: A Versatile Crop Integrating Nutrition, Oil Production and Natural Fibre for Sustainable Agriculture

¹Eshant Kumar Sukdeve and ²Richa Chaudhary

¹Subject Matter Specialist, Agricultural Extension, IGKV- Krishi Vigyan Kendra, Dantewada (C.G.)

²Assistant Professor, College of Agriculture & Research Station, Mahasamund, IGKV (C.G.)

Article ID: 24006

Abstract

Linseed (*Linum usitatissimum* L.) or flaxseed, is an ancient cultivated crop known for its versatile applications in food, oil and industrial products. Its seeds are rich in oil (35–46%), proteins, dietary fibre and bioactive compounds like lignans and flavonoids, which enhance its functional properties. Linseed oil is valued for its high alpha-linolenic acid (ALA) content, linked to lower risks of cardiovascular diseases, cancer and inflammation. Additionally, linseed's by-products, such as seedcake, fibres and shives have significant industrial uses and contribute to food preservation and pharmaceuticals. Cultivating linseed supports sustainable agriculture due to its adaptability and low input needs, making it a promising crop for enhancing agricultural diversification and rural economic growth amid rising demand for eco-friendly products.

Introduction

Linseed (*Linum usitatissimum* L.) or flaxseed, is an ancient crop noted for its diverse applications in food, oil and fibre production. The oil derived from flaxseeds is praised for its high omega-3 fatty acids, particularly alpha-linolenic acid, which is essential for human health and chronic disease prevention. Biochemical studies have revealed numerous bioactive compounds within linseed oil that have nutritional, cosmetic and pharmaceutical benefits. Besides oil, linseed yields valuable by-products such as seedcakes, fibres and shives, which hold increasing industrial importance. Recent advances in analytical techniques have identified beneficial compounds in these by-products, including phenylpropanoids, terpenoids and lignocellulosic biomass, known for their antibacterial, antifungal, anticancer and anti-inflammatory properties. This diversification broadens linseed's industrial applications, extending to functional foods, nutraceuticals, polymer composites, biofuels and pharmaceuticals. Furthermore, linseed cultivation promotes sustainable farming practices due to its adaptability to various agro-climatic conditions and minimal input requirements, making it fit for small and marginal farmers. India is a major linseed producer,

primarily in rainfed areas across numerous states. With increasing global interest in healthy diets, plant-based nutrition, and sustainable materials, linseed is re-emerging as a highly valuable crop with significant agricultural and industrial potential.

Origin and Distribution

Linseed is believed to have originated in the Middle East and later spread to Europe and other regions of the world through domestication and cultivation. Over time, selective breeding resulted in the development of two main forms of the crop: oilseed flax (linseed) and fibre flax. These two forms differ significantly in their morphological characteristics and production objectives. Oilseed flax plants are usually shorter and more branched, while fibre flax plants are taller and less branched to facilitate the production of long and strong fibres (Green & Marshall, 1984; Singh *et al.*, 2011).

Today, linseed is cultivated in many parts of the world including Canada, Russia, China, India and several European countries. Canada is currently one of the leading producers and exporters of linseed, followed by Russia and Kazakhstan (FAO, 2018). In India, the crop is mainly grown in states such as Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Bihar, Rajasthan and Maharashtra, mostly under rainfed conditions (ICAR, 2020).

Nutritional and Biochemical Composition of Linseed

Linseed seeds are highly nutritious and contain a balanced composition of oil, proteins, carbohydrates, dietary fibre and minerals. The seeds generally contain 35–46% oil, 20–25% protein, and about 25–30% carbohydrates, making them an excellent source of energy and nutrients (Kajla *et al.*, 2015; Goyal *et al.*, 2014).

One of the most important components of linseed oil is alpha-linolenic acid (ALA), an essential omega-3 fatty acid that plays a vital role in human health. In addition, linseed seeds contain several biologically active compounds, including lignans, phenolic acids, flavonoids and dietary fibre, which contribute to their functional and medicinal properties (Oomah, 2001; Goyal *et al.*, 2014).

Among these compounds, Secoisolariciresinol Diglucoside (SDG) is the most abundant lignan present in flaxseed. This compound exhibits strong antioxidant activity and has been associated with reduced risk of cardiovascular diseases, hormonal disorders and certain types of cancer (Adlercreutz, 2007; Kajla *et al.*, 2015).

Linseed Oil and Its Applications

Linseed oil is one of the most valuable products derived from flax seeds and has extensive applications in both food and industrial sectors. Due to its high content of polyunsaturated fatty acids, especially omega-3 fatty acids, linseed oil is widely recommended as a health-promoting dietary supplement (Goyal *et al.*, 2014).

In the pharmaceutical and cosmetic industries, linseed oil is used in skin-care products, therapeutic formulations and nutraceutical supplements due to its anti-inflammatory and antioxidant properties (Kajla *et al.*, 2015).

Seedcake (Linseed Expeller) and Its Industrial Importance

The residue remaining after oil extraction from flax seeds is known as linseed seedcake or expeller. This by-product is rich in proteins, lignans and phenolic compounds and therefore has considerable economic value. Linseed seedcake extracts contain compounds such as ferulic acid, caffeic acid and coumaric acid, which possess strong antioxidant and antimicrobial properties (Zuk *et al.*, 2015).



Furthermore, linseed seedcake has been used to prevent lipid oxidation in meat products, thereby improving the shelf life and nutritional quality of processed foods (Kajla *et al.*, 2015).

Fibre Production and Industrial Uses

Flax fibre obtained from the stem of the plant is one of the strongest natural fibres available. Traditionally, flax fibres were used to produce linen textiles, ropes and fabrics. However, in recent years, new industrial applications of flax fibre have emerged. These fibres offer an environmentally friendly alternative to synthetic fibres such as glass and carbon fibres.



Additionally, flax-based fabrics have shown promising results in biomedical applications such as wound dressings and tissue engineering, as they exhibit good compatibility with human cells and low cytotoxicity (Zuk *et al.*, 2015).

Shives and Their Bioactive Properties

Shives are the woody inner portions of the flax stem that remain after fibre extraction. These materials were once considered agricultural waste but are now recognized as valuable sources of lignocellulosic biomass and bioactive compounds.

Linseed shives consist mainly of cellulose, hemicellulose, lignin and phenolic compounds. They also contain substances such as vanillin and ferulic acid, which have antioxidant and antimicrobial properties (Zuk *et al.*, 2015).

Because of these beneficial properties, shives are being investigated for use in biofuel production, biodegradable materials, mushroom cultivation and pharmaceutical products. Their utilization contributes to the development of a circular bioeconomy and sustainable resource management.

Multipurpose Applications of Linseed

The linseed plant demonstrates exceptional versatility because nearly every component of the plant can be utilized for various purposes. Seeds are used for food and oil production, fibres are used in textiles and industrial composites, seedcakes are utilized in animal feed and pharmaceutical products and shives are used as raw materials for bioenergy and construction materials.

This comprehensive utilization makes linseed an important crop for sustainable agriculture and value-added product development. The development of innovative products from linseed biomass has the potential to increase farmers' income while reducing agricultural waste (Kajla *et al.*, 2015; Zuk *et al.*, 2015).

Future Prospects of Linseed Cultivation

Recent advances in plant biotechnology and genomics have opened new possibilities for improving linseed productivity and quality. The sequencing of the flax genome has facilitated research on crop improvement, enabling scientists to develop varieties with improved oil composition, disease resistance, and fibre quality (Wang et al., 2012).

Moreover, growing global demand for functional foods, plant-based omega-3 fatty acids and natural fibres is expected to enhance the commercial importance of linseed in the future. With appropriate research support, improved varieties and better agronomic practices, linseed cultivation can significantly contribute to sustainable agricultural systems and rural economic development.

Conclusion

Linseed (*Linum usitatissimum* L.) is a highly versatile crop that offers a unique combination of food, oil, fibre and industrial raw materials. Its seeds provide nutritionally rich oil containing essential omega-3 fatty acids, proteins and antioxidants that contribute significantly to human health. In addition to its dietary importance, linseed oil has extensive industrial applications in paints, coatings, cosmetics and pharmaceutical products.

The by-products of linseed processing, including seedcake and shives, are also valuable resources containing bioactive compounds with antimicrobial, antioxidant, and medicinal properties. Furthermore, flax fibres represent an environmentally friendly alternative to synthetic materials and are increasingly used in textiles, construction materials, and automobile components. The complete utilization of the linseed plant demonstrates its potential to support sustainable agriculture, reduce waste, and generate value-added products for multiple industries. With increasing global demand for functional foods and eco-friendly materials, linseed cultivation is expected to regain its importance in modern agriculture (Kajla *et al.*, 2015; Zuk *et al.*, 2015).

References:

1. Adlercreutz, H. (2007). Lignans and human health. *Critical Reviews in Clinical Laboratory Sciences*, 44(5–6), 483–525.
2. Food and Agriculture Organization (FAO). (2018). *FAOSTAT statistical database*. Food and Agriculture Organization of the United Nations.
3. Goyal, A., Sharma, V., Upadhyay, N., Gill, S., & Sihag, M. (2014). Flax and flaxseed oil: An ancient medicine and modern functional food. *Journal of Food Science and Technology*, 51(9), 1633–1653.

4. Green, A. G., & Marshall, D. R. (1984). Isolation of induced mutants in linseed (*Linum usitatissimum* L.) having reduced linolenic acid content. *Euphytica*, 33(2), 321–328.
5. Kajla, P., Sharma, A., & Sood, D. R. (2015). Flaxseed—A potential functional food source. *Journal of Food Science and Technology*, 52(4), 1857–1871.
6. Oomah, B. D. (2001). Flaxseed as a functional food source. *Journal of the Science of Food and Agriculture*, 81(9), 889–894.
7. Singh, K. K., Mridula, D., Rehal, J., & Barnwal, P. (2011). Flaxseed: A potential source of food, feed and fiber. *Critical Reviews in Food Science and Nutrition*, 51(3), 210–222.
8. Wang, Z., Hobson, N., Galindo, L., Zhu, S., Shi, D., McDill, J., Yang, L., Hawkins, S., Neutelings, G., Datla, R., Lambert, G., Galbraith, D., Grassa, C., Geraldles, A., Cronk, Q., Cullis, C., Dash, P., Kumar, P., Cloutier, S., & Sharpe, A. (2012). The genome of flax (*Linum usitatissimum*) assembled de novo from short shotgun sequence reads. *The Plant Journal*, 72(3), 461–473.
9. Żuk, M., Richter, D., Matuła, J., & Szopa, J. (2015). Linseed, the multipurpose plant. *Industrial Crops and Products*, 75, 165–177.

HARNESSING ROOTSTOCK POTENTIAL FOR SUSTAINABLE FRUIT PRODUCTION IN WARM REGIONS

Nivedita^{1*} Riya verma² Anjali³

¹M.Sc. Student, Department of Fruit Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

²M.Sc. Student, Department of Food Science and Technology, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

³M.Sc. Student, Department of Fruit Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

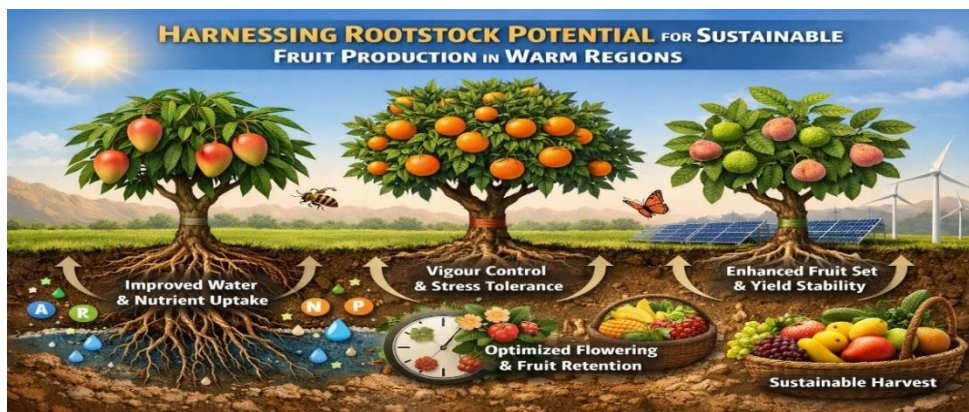
Corresponding author email- niveditat940@gmail.com

Article ID: 24007

1. INTRODUCTION

Rootstocks are an integral component of fruit crop production systems, exerting profound effects on tree growth, fruit quality and overall orchard productivity. The significance of rootstock selection is underscored by its influence on tree vigour, precocity, yield efficiency and resilience to various soil and climatic conditions (Robinson et al., 2016). Effective rootstock selection is essential for optimizing orchard performance, enhancing sustainability and meeting the diverse needs of growers and consumers. In tropical and subtropical regions - where soils may vary from alkaline to saline and climatic conditions may shift from extreme heat to periodic drought-effective rootstock selection requires assessing adaptability to these environmental factors (Hancock et al. 2015). Strong rootstock–scion compatibility is essential for developing healthy graft unions and ensuring sustained orchard performance over many years. Rootstocks also provide resistance against soil-borne pathogens, insect pests and physiological disorders, reducing reliance on chemical inputs and supporting more sustainable fruit production systems. The role of rootstocks and its use in different fruit crops has significant impact on fruit crop production by influencing canopy architecture, nutritional uptake, flowering, yield and fruit quality.

EFFECT OF STOCK ON SCION CULTIVARS



List of resistant/ tolerant rootstocks in fruit crops:

Crop	Rootstock	Resistant traits
Mango	13-1, Olour, Bappakai, Gomera-1, 13/3	Tolerant to salinity
	Carabao	Tolerant to wilt
Guava	<i>Psidium friedrichsthalianum</i> , <i>P. cattleianum</i> var. <i>lucidum</i> , <i>Psidium guineense</i>	Resistance to root-knot nematode
Avocado	G755C13-1	Salt tolerant
	Duke 7 and G6	Resistance to <i>P. cinnamomi</i>
Loquat	Anger	Tolerance to Saline conditions

2.1 How Rootstock help to induce Dwarfness

Dwarfing might be caused by water supply restrictions to the scion induced by anatomical characteristics of the rootstock (Beakbane, 1956; Aykinson et al., 2003). Dwarfing might be caused by partial incompatibility between the scion and the rootstock which may alter the transport of minerals and hormones (Webster, 2004).

Rootstocks for Dwarfing and High-Density Planting

Mango (<i>Mangifera indica</i>)	Vellaikolamban (Vellai Kulamban), Olour, Ambelavi, Kalapady
Citrus (<i>Citrus spp.</i>)	Flying Dragon (<i>Ponciru trifoliata</i> orange var. <i>monstrosa</i>)

Guava	<i>Psidium pumilum</i> , Pusa Srijan, Aneuploid-82
Sapota / Chikoo	Khirmi (<i>Manilkara hexandra</i>)

2.2 Tree Size and Vigour

Tree size and vigour are important factors determining orchard productivity. Rootstocks influence plant growth by affecting root system development, water absorption and nutrient uptake. Dwarfing rootstocks reduce canopy size and vegetative growth, making them suitable for high-density planting systems. In contrast, vigorous rootstocks develop extensive root systems that enhance drought tolerance and nutrient absorption. In fruit crops such as mango, citrus and guava, rootstock selection significantly influences tree architecture and yield efficiency. For example, *Poncirus trifoliata* is commonly used in citrus because it controls tree size and improves tolerance to environmental stresses.

2.3 Precocity in Flowering and Fruiting

Precocity in flowering and fruiting refers to the early initiation of reproductive growth in fruit crops due to the influence of suitable rootstocks. In warm regions, vigorous vegetative growth often delays flowering, but appropriate rootstocks help shorten the juvenile phase and promote early fruiting. Dwarfing and semi-dwarfing rootstocks regulate plant vigor, improve nutrient and water uptake and maintain hormonal balance, encouraging early floral bud differentiation. In crops like Mango, Guava and Citrus, grafting onto suitable rootstocks ensures earlier bearing, higher productivity and quicker economic returns, supporting sustainable fruit production systems.

2.4 Fruit set and yield

Rootstock-scion interactions play an important role in determining fruit set and yield in grafted fruit crops, especially under warm climatic conditions. Grafting modifies physiological and hormonal communication between the rootstock and scion, influencing flowering and fruit development (Goldschmidt, 2014). Rootstocks also regulate water and nutrient uptake, tree vigour and canopy architecture, which directly affect floral initiation, fruit retention and final yield. In warm regions, where excessive vegetative growth may reduce fruit set, dwarfing or semi-vigorous rootstocks help maintain a balanced vegetative–reproductive growth, thereby improving yield efficiency (Webster, 2004). The physiological and historical basis of stock–scion interactions has been extensively described by (Mudge et al.,2009). Hence, selecting appropriate rootstocks is

essential for improving fruit set and achieving sustainable yields in warm-region fruit production systems.

2.5 Nutrient Status of Scion

The nutrient status of the scion is strongly influenced by the rootstock onto which it is grafted. Rootstocks regulate the uptake and translocation of water and essential nutrients from the soil to the scion, thereby affecting plant growth and productivity. Rootstocks differ in their ability to absorb and transport nutrients such as nitrogen, phosphorus, potassium, calcium and magnesium, which influence scion growth, flowering and fruiting (Hartmann et al., 2018). Dwarfing rootstocks can modify mineral nutrition and improve yield efficiency and fruit quality (Webster, 2004). Additionally, variations in rootstock genotype affect nutrient accumulation in leaves and fruits, ultimately influencing productivity and sustainability in fruit crops (Zhang et al., 2016).

Conclusion

Rootstocks play a crucial role in improving productivity and sustainability in fruit crops grown in tropical and subtropical regions. They influence tree size, canopy structure, nutrient uptake, flowering behaviour, yield and fruit quality. By improving tolerance to environmental stresses such as drought and salinity, rootstocks help plants perform better under challenging conditions. Disease-resistant rootstocks also reduce dependence on chemical control measures, making fruit production more environmentally friendly. Furthermore, dwarf and semi-dwarf rootstocks enable high-density planting systems that improve orchard management and productivity. However, rootstock performance may vary depending on local environmental conditions. Therefore, careful evaluation of rootstocks under regional conditions is essential before large-scale adoption. Future research should focus on developing rootstocks with improved stress tolerance, better compatibility with scion cultivars and suitability for modern orchard systems.

References

1. Atkinson C J, Else M A & Taylor L. (2003). Interactions between rootstock, inter-stem and scion xylem vessel characteristics of peach trees growing on rootstocks with contrasting size-controlling characteristics. *Annals of Botany*. 91(4): 707–714. [DOI:10.1093/aob/mcg076](https://doi.org/10.1093/aob/mcg076).
2. Watson D J & Wilson J. H. (1956). An analysis of the effects of infection with leaf-roll virus on the growth and yield of potato plants and of its interactions with nutrient supply

and shading. *Annals of Applied Biology*. 44(3): 517–532. <https://doi.org/10.1111/j.1744-7348.1956.tb02134.x>

3. Castle, W. S. (2010). A career perspective on citrus rootstocks, their development, and commercialization. *HortScience*. 45(1):11–15.
4. Goldschmidt E E. (2014). Plant grafting: New mechanisms, evolutionary implications. *Frontiers in Plant Science*. 5: 727.
5. Hancock J F, Hokanson S C, & Finn C E. (2015). Rootstock breeding, selection, and management in the United States. *Horticultural reviews*. 43:335–375).
6. Mudge K, Janick J, Scofield S, & Goldschmidt E E. (2009). A history of grafting. *Horticultural Reviews*. 35: 437–493.
7. Robinson T L, Lakso A N, & Robinson T L. (2016). Advances in apple culture: Rootstocks. *Horticultural reviews*. 44:125–213).
8. Rasool A, Mansoor S, Bhat K M, Hassan G I, Baba T R, Alyemeni M N & Ahmad P. (2020). Mechanisms underlying graft union formation and rootstock–scion interaction in horticultural plants. *Frontiers in Plant Scienc.* 11, 590847. <https://doi.org/10.3389/fpls.2020.590847>
9. Webster A D. (2004). Vigour mechanisms in dwarfing rootstocks for temperate fruit trees. *Horticultural Reviews*. 30: 1–33.

National Turmeric Board: A Landmark Shift in India's Agricultural Policy and Export Strategy

¹Taniya Soni, ²Hem Prakash Verma, ³Vishalakshi Choubey and ⁴Eshika Soni

^{1&4}M.Sc. Student, Department of Agricultural Extension Education, CoA, Raipur (CG)

²Senior Research Fellow, Farmer FIRST Project, ICAR-National Institute of Biotic Stress Management, Raipur (CG)

³PhD Scholar, Department of Agricultural Extension Education, CoA, Raipur (CG)

Article ID: 24008

Abstract

The formal inauguration of the National Turmeric Board (NTB) in Nizamabad, Telangana, on June 29, 2025, represents a landmark shift in India's agricultural policy, providing dedicated institutional oversight to a sector previously governed by the general Spices Board. This manuscript examines strategic evolution of Nizamabad, recognized as the 'Turmeric Capital of India' for its prolific production of high-curcumin cultivars from a traditional agricultural center into a sophisticated global gateway. Backed by an initial Rs. 200 crore corpus, the NTB is tasked with achieving an ambitious \$1 billion global export target by 2030 through a multifaceted roadmap: doubling export valuations, implementing rigorous Integrated Pest Management (IPM) and 'Zero-Residue' standards to meet international safety protocols and securing Geographical Indication (GI) status for the hallmark 'Armor' variety. However, the Board's inaugural year has been marked by significant structural tests, notably the 2026 West Asia crisis, which saw regional tensions and shipping disruptions cause local turmeric prices to tumble by approximately Rs. 4,000 per quintal.

Keywords: National Turmeric Board, Curcumin, Nizamabad and Telanagana.

Introduction:

On June 29, 2025, the union home minister formally inaugurated the National Turmeric Board (NTB) headquarters in Nizamabad, Telangana (Ministry of Commerce and Industry, 2025). This landmark initiative addresses a 40-year advocacy for specialized institutional oversight for the turmeric sector. Under the leadership of its first Chairperson, Palle Ganga Reddy, the Board is backed by an initial corpus of Rs. 200 crores. The NTB is tasked with driving India's \$1 billion global export roadmap (Indian Council for Research on International Economic Relations) by 2030, focusing on doubling export valuations, implementing Integrated Pest Management (IPM)

standards, and solidifying Telangana's position as a premier global hub for the 'Golden Spice'. Nizamabad's designation as the 'Turmeric Capital of India' is supported by its status as a premier commercial hub and a prolific producer of the Armour cultivar, valued internationally for its superior curcumin content (Jetty Mrudula Patel, 2022). Agricultural data indicates a cultivation footprint of 10,000 hectares, yielding an annual production of 1.33 lakh tones. Beyond its medicinal and cosmetic utility, the crop represents a vital economic pillar for Telangana. The localization of the National Turmeric Board's administrative headquarters in Nizamabad formalizes the district's role in the global supply chain. This move effectively bridges the gap between primary producers and international trade frameworks, facilitating the attainment of the government's \$1 billion global export target.

The Current Crissies

- **The West Asia Factor:** Early in 2026, Telangana's turmeric industry was severely impacted by the West Asia Factor, as the closure of the Strait of Hormuz and intensifying regional tensions stymied exports to the Gulf (Pulloor, 2026). Nearly 25 per cent of India's turmeric has historically been shipped to West Asian markets, but the current shipping delays and skyrocketing insurance costs have resulted in a large supply backlog in regional mandis (Deccan Chronicle, 2024). Consequently, prices at the Nizamabad market have tumbled from a peak of Rs. 18,000 per quintal to nearly Rs. 14,000, forcing many farmers into distress sales or desperate storage of their 'Golden Spice' while they wait for the National Turmeric Board to activate price stabilization protocols.
- **The Board's Role:** As of March 2026, Telangana's farmers are demanding that Price Stabilization Funds be activated immediately in order to mitigate the economic effects of the West Asia conflict, posing the first significant structural test for the National Turmeric Board. Growers are pleading with the Board to go beyond its administrative function and take direct action in the market to stop widespread distress sales, as local prices in Nizamabad have fallen by around Rs. 4,000. Farmers are demanding a state-backed 'economic shield' that guarantees a minimum procurement price and subsidized cold storage, ensuring that the 40-year fight for a dedicated Board culminates in real financial security amid periods of global instability.

From Spice to Science

- **Beyond the Kitchen:** The National Turmeric Board is redefining Telangana's harvest as a high-tech industrial commodity for the multibillion-dollar pharmaceutical and cosmetic

industries, going beyond its traditional role in the culinary realm (National Turmeric Board Launched). The Board is shifting the value chain from raw powder to refined extracts used in life-saving medications and high-end organic skincare by creating local extraction facilities in Nizamabad and offering incentives for the growth of high-curcumin types (AgroSpectrum India, 2025). Telangana's farmers will now be vital suppliers to the global wellness sector, where refined turmeric derivatives fetch much greater prices than the raw agricultural product, thanks to this strategic shift.

- **Quality Control:** A strict Quality Control framework focused on Integrated Pest Management (IPM) to satisfy the strict Maximum Residue Limits (MRL) of European and US markets is a key component of the National Turmeric Board's 2026 agenda. The Board is methodically lowering pesticide residues that formerly caused international shipping rejections by substituting biological agents, pheromone traps, and solar-powered drying equipment for conventional chemical-heavy sprays (The Hindu, 2026). The Board is giving farmers the 'Zero-Residue' certifications required to move from selling bulk commodities to supplying the most stringent pharmaceutical and food safety regulations in the world by setting up mobile testing labs in the Nizamabad-Nirmal belt.
- **The 'Armor' Advantage:** The 'Armor Advantage' is the result of the National Turmeric Board's calculated efforts to get Telangana's hallmark turmeric a Geographical Indication (GI) designation, turning it into a high-end international brand (Metro India, 2024). The Board is establishing a legal barrier that forbids imitation and demanding a substantial price premium by utilizing the distinct biochemical profile and 90-year cultivation history of the 'Erra Guntur' type developed in Nizamabad's particular soil. In order to transform Armor turmeric from a volatile bulk commodity into a protected specialty product and guarantee that the farmers of Nizamabad, Jagtial, and Nirmal receive international recognition and monetary compensation their distinctive history merits, this GI certification is essential.

The roadmap to 2030

- **The \$1 Billion Target:** The goal of the government's '1 billion Dollar Target' is to increase India's turmeric exports from \$225 million to \$1 billion by 2030. High-value Curcumin extracts, oils, and nutraceuticals that fetch premium pricing in the US and European markets will replace bulk raw exports under this program. The National Turmeric Board is streamlining the supply chain through cooperatives like NCEL with

the support of a ₹200 crore research fund and a goal to double national production to 2 million tonnes. This will ensure that the ‘Golden Spice’ becomes a globally recognized pharmaceutical powerhouse rather than just a kitchen staple.

- **Value Addition:** The National Turmeric Board’s focus on ‘Value Addition’ is a strategic shift from selling low-margin raw ‘fingers’ to high-margin Curcumin extracts, which can command a price premium of 30 to 40 per cent over traditional agricultural sales. By facilitating the setup of advanced extraction and chromatography units in Nizamabad, the Board is helping local enterprises transform 30 tons of raw powder into high-purity, 95% standardized curcuminoids valued at thousands of rupees per kilogram. By entering the ‘high-margin chemistry’ of spices, Telangana's turmeric sector will be able to fully capitalize on the global pharmaceutical and nutraceutical markets, where growth is mostly driven by refined extracts rather than raw spices (ICRIER; AgroSpectrum India, 2025).

Conclusion

Telangana is evolving from a prospect rich in minerals to a major participant in India's gold economy. The state is going beyond its traditional coal and granite foundations to access substantial gold reserves in areas like Gadwal-Narayanpet and the Kosgi Block, with a boom in domestic exploration in 2026. But the real worth of this ‘gold in the soil’ depends on international confidence. The state has incorporated strict purity infrastructures, such as the 6-digit HUID (Hallmark Unique Identification) system and required BIS Hallmarking, to close this gap and guarantee that every gram is traceable and validated. Telangana is establishing itself as a reliable global center for high-purity gold and artisanal excellence by fusing cutting-edge mining technology with top-notch certification standards.

References:

1. AgroSpectrum India. (2025, December 19). Turmeric’s next growth phase takes shape at India’s first value chain summit. <https://agrospectrumindia.com/2025/12/19/turmeric-next-growth-phase-takes-shape-at-indias-first-value-chain-summit.html>
2. Deccan Chronicle. (2024, October 16). War in West Asia causes turmeric prices to tumble in Nizamabad market. <https://www.deccanchronicle.com/southern-states/telangana/war-in-west-asia-causes-turmeric-prices-to-tumble-in-nizamabad-market-1943425>
3. Indian Council for Research on International Economic Relations (ICRIER). (n.d.). Making India the global hub for turmeric: Key findings and roadmap. <https://icrier.org/pdf/Making-India-the-Global-Hub-for-Turmeric.pdf>

4. Jetty Mrudula Patel. (2022). Value chain analysis of turmeric in Nizamabad district of Telangana. Master's project report, Swami Keshwanand Rajasthan Agricultural University. Krishikosh. <https://krishikosh.egranth.ac.in/handle/1/5820689931>
5. Metro India. (2024, December 3). Armour turmeric receives GI registry acceptance: A major milestone for Telangana's turmeric farmers. <https://www.metroindia.net/news/articlenews/armoor-turmeric-receives-gi-registry-acceptance-30071>
6. Press Information Bureau. (2023, October 4). Government of India notifies the constitution of the National Turmeric Board. Ministry of Commerce & Industry. <https://pib.gov.in/PressReleasePage.aspx?PRID=1964083>
7. Pulloor, N. (2026, January 19). War in West Asia causes turmeric prices to tumble in Nizamabad market. Deccan Chronicle. <https://www.deccanchronicle.com/southern-states/telangana/war-in-west-asia-causes-turmeric-prices-to-tumble-in-nizamabad-market-1943425>
8. The Hindu. (2025, June 29). Turmeric Board will strengthen farmers financially with new markets opening: Amit Shah. <https://www.thehindu.com/news/national/telangana/turmeric-board-will-strengthen-farmers-financially-with-new-markets-opening-amit-shah/article69752601.ece>