

Aeroponic Technology: Prospects for Quality Seed and Planting Material Production in Vegetables

Priyanka Kumari^{1*}, Monisha Thangavel¹, Anusha K R¹ and Rajinder Kumar Dhall¹

¹*Department of Vegetable Science, College of Horticulture & Forestry, Punjab Agricultural University, Ludhiana, Punjab, India*

Corresponding Author

Priyanka Kumari

Email: pk2969728@gmail.com



OPEN ACCESS

Keywords

Aeroponics, Vegetable Seed Production, Soilless Cultivation, Sustainable Agriculture, Nutrient Misting

How to cite this article:

Kumari, P., Thangavel, M., Anusha, K. R. and Dhall, R. K. 2026. Aeroponic Technology: Prospects for Quality Seed and Planting Material Production in Vegetables. *Vigyan Varta* 7 (06): 19-23.

ABSTRACT

Aeroponics is an advanced soilless cultivation technique that enables efficient and disease-free vegetable seed production. By suspending plant roots in air and supplying nutrients through fine misting, aeroponics ensures optimal oxygenation, uniform growth and high genetic purity. It offers major advantages over soil-based systems including higher multiplication rates, resource efficiency and year-round production. Studies on crops such as potato, tomato, cucumber, and pepper demonstrate significant improvements in yield, seed quality, and economic returns. Integration with automation and IoT technologies further enhances control and sustainability, positioning aeroponics as a key innovation in modern seed production systems. In India, aeroponics shows strong potential for early-generation seed multiplication and production of disease-free planting material within organized seed production programmes. The technology can support sustainable intensification by improving input-use efficiency and ensuring consistent supply of high-quality vegetable seeds under controlled environments.

INTRODUCTION

The availability of high-quality vegetable seeds and planting material is a critical factor determining productivity, profitability and sustainability of vegetable production systems. In India, the demand for genetically pure, vigorous and disease-free seeds has increased substantially due to the expansion of hybrid cultivation, protected farming and intensive vegetable production practices. However, conventional soil-based seed production systems often encounter major constraints such as soil-borne pathogens, nematode infestation, uneven nutrient availability, climatic variability and declining soil health. These challenges frequently result in poor seed quality, reduced multiplication rates and inconsistency in planting material, ultimately affecting crop performance and farmer income.

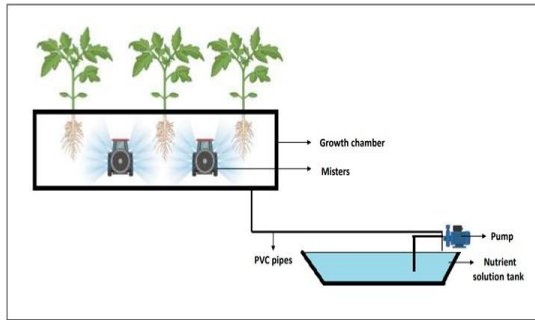
India's vegetable seed sector, supported by ICAR institutes, State Agricultural Universities (SAUs) and public-private seed companies, follows a structured seed multiplication chain involving nucleus, breeder, foundation and certified seed production. Maintaining genetic purity and producing disease-free planting material at early stages of this chain is particularly challenging, especially for vegetatively propagated crops like potato and for hybrid vegetable seed production where healthy parental lines are essential. Traditional propagation methods are often slow and susceptible to pathogen build-up, highlighting the need for innovative and controlled production technologies.

Soilless cultivation systems have emerged as promising alternatives to overcome these limitations by enabling precise management of plant growth conditions. Among these, aeroponics represents an advanced cultivation technique in which plant roots are suspended

in air and periodically supplied with a fine nutrient mist. In recent years, aeroponic technology has gained attention in India for applications such as potato mini-tuber production, maintenance of hybrid parental lines and rapid multiplication of disease-free vegetable planting material. The technology fits well within modern seed production frameworks by supporting early-generation seed multiplication and ensuring uniform, high-quality propagules. Furthermore, integration with protected cultivation, automation and sensor-based monitoring systems allows year-round production independent of seasonal constraints, making aeroponics a potential tool for strengthening sustainable and climate-resilient seed systems. Considering the growing need for efficient seed production technologies, this article discusses the principles, advantages, applications and future prospects of aeroponic systems for quality seed and planting material production in vegetable crops, with particular emphasis on their relevance under Indian agricultural conditions.

Principle of aeroponic cultivation

In aeroponic systems, plants are anchored in small holders or lattice pots while their roots hang freely in a closed chamber. This chamber periodically releases a fine mist containing dissolved nutrients, ensuring optimal oxygenation and hydration of roots. The technique maximizes root exposure to oxygen (100%), enhances photosynthetic efficiency and maintains precise nutrient absorption through automated pH and conductivity control. Unlike hydroponics, it uses no growth medium, preventing disease spread and facilitating easy access for root inspection and nutrient monitoring.



Advantages of Aeroponics in Seed Production

Aeroponics provides multiple agronomic and economic benefits in vegetable seed production, including:

- **Higher Multiplication Rate:** Aeroponics allows rapid multiplication of vegetatively propagated crops like potatoes and sweet potatoes. A single potato plant can produce over 100 minitubers per season compared to 8–10 in soil-based methods.
- **Disease-Free Seed Production:** Since plants are grown without soil, aeroponic systems eliminate the risk of soil-borne pathogens such as fungi, nematodes and bacteria. The sterile environment ensures the production of disease-free, clean planting material which is crucial for seed industries.
- **Resource Efficiency:** Aeroponics consumes up to 95% less water and 70% less fertilizer than conventional systems by recirculating nutrient solutions and reducing leaching losses. For instance, producing 1 kg of tomatoes typically requires 20 litres of water in aeroponics compared to 200–400 litres in soil cultivation.
- **Enhanced Seed Quality:** Controlled misting cycles lead to uniform growth, better seed filling, and higher germination percentages.
- **Sustainability and space efficiency:** The system’s vertical design allows high-density planting, making it environmentally

friendly and suitable for urban and peri-urban seed farms.

- **Year-Round Production:** Aeroponics facilitates continuous, year-round seed production, independent of seasonal variations. This enables consistent seed supply and helps meet the increasing market demand.

Comparison between Conventional and Aeroponic Systems for Vegetable Seed and Planting Material Production

<i>Aspects</i>	<i>Conventional Soil-Based Seed Production</i>	<i>Aeroponic Seed/Planting Material Production</i>
Growing medium	Soil or soil-based substrates	No soil; roots suspended in air
Disease risk	High risk of soil-borne pathogens, nematodes and bacteria	Minimal risk due to controlled and hygienic environment
Genetic purity maintenance	Difficult due to environmental variability and contamination	Easier maintenance under controlled conditions
Multiplication rate	Low to moderate	Very high multiplication rate (e.g., potato mini-tubers)
Water use efficiency	High water requirement with losses through leaching	Up to 90–95% water saving through recirculation
Fertilizer use efficiency	Nutrient losses common	Precise nutrient delivery with minimal wastage
Environmental control	Limited control over temperature, humidity and nutrients	Precise control through automation and sensors
Seed/planting material quality	Variable depending on field conditions	Uniform, disease-free and physiologically superior
Seasonal dependency	Highly season dependent	Enables year-round production
Labour requirement	Moderate manual labour	Skilled labour required for monitoring and management
Initial investment	Low to moderate	High initial setup cost
Technical expertise	Conventional farming knowledge sufficient	Requires training and technical understanding

Suitability	Suitable for large-scale certified production	Best suited for nucleus, breeder and foundation seed stages
Power dependency	Low	High (continuous power supply required)
Adoption level in India	Widely practiced	Mostly research institutions and protected cultivation units

Applications in Vegetable Crops

- **Tomato (*Solanum lycopersicum*)** – Hybrid seed production in soilless/aeroponic systems: A trial at the University of Agricultural Sciences, Bengaluru (India) compared conventional soil production (M1) vs hydroponics (M2) vs aeroponics (M3) for two parental lines and two seed-treatments. Aeroponics showed significantly higher plant height, fruit weight and test weight of seeds. Also, an economic-analysis found aeroponics produced gross returns ~ 94.68% higher than conventional, with benefit-cost ratio 2.08 (Rajatha *et al* 2022).
- **Potato (*Solanum tuberosum*)** – mini-tuber / seed-tuber production: A long-term evaluation at the ICAR-Central Potato Research Institute (Gwalior) of 17 varieties in aeroponic system found emergence rates 85-99% and demonstrated the potential for basic seed production (Sadawarti *et al* 2023).
- **Leafy vegetables and fruit bearing vegetable crops** - A comparative study of aeroponic vs field growth for leafy vegetables (basil, chard, red kale, parsley) and fruit bearing vegetables (bell pepper, cherry tomato, cucumber, squash) was done by Chandra *et al* 2014. They found that the yield increased by ~19 % (basil), ~53 % (bell pepper), ~35 % (cherry tomatoes), ~7 % (cucumber) when grown in aeroponics as compared to soil cultivation.

- **Capsicum / Pepper** - Del Valle-Echevarria *et al* 2019 developed and validated aeroponic cloning protocols for *Capsicum* spp. demonstrating fast root formation from cuttings and a reliable route to produce uniform parental lines or propagation material for seed production programmes. This approach was found useful for maintaining pure parental lines for controlled hybrid seed production.
- **Cucumber** - Jamshidi *et al* 2020 optimized misting parameters in a columnar aeroponic system for cucumber, testing different spray rates and durations. Using response surface methodology, the best combination was found at a spray rate of $\approx 233 \text{ mL min}^{-1}$ and duration of ≈ 16 minutes, giving a yield of $2.96 \text{ kg plant}^{-1}$ and water use efficiency of 110.37 kg m^{-3} . The research concluded that precise control of misting significantly improves both yield and resource efficiency. It highlights aeroponics as a water-saving and high-productivity technique for cucumber cultivation in controlled environments.
- **Jalapeño pepper** - Controlled trials characterized vegetative growth and fruiting of jalapeño in aeroponics, documenting root/leaf development and validating aeroponics as a robust platform for producing uniform fruiting plants which is useful for seed production contexts where synchronized flowering and clean parental stock matter (Martinez-Nolasco *et al* 2023).

Limitations and Practical Challenges of Aeroponics under Indian Conditions

Despite its significant potential, large-scale adoption of aeroponic technology in India is still at a developing stage due to several technical, economic and operational constraints. One of the primary limitations is the high initial investment required for

establishing aeroponic units, including protected structures, misting systems, pumps, sensors and automation components. For small and marginal farmers, the capital cost remains a major barrier without institutional support or subsidy schemes. Another important challenge is the requirement of uninterrupted electricity supply and technical expertise for system management. Aeroponic systems depend on precise misting intervals and nutrient delivery; even short power failures can lead to rapid root desiccation and plant loss. In many rural areas, inconsistent power supply and limited access to trained personnel restrict large-scale adoption at the farm level.

Maintenance and operational management also demand careful monitoring of nutrient solution composition, pH and electrical conductivity. Improper nutrient balance or clogging of misting nozzles due to water impurities may reduce system efficiency and plant performance. Additionally, farmers require specialized training to operate and troubleshoot aeroponic systems, which differs considerably from conventional cultivation practices. Under Indian conditions, environmental factors such as high summer temperatures and humidity fluctuations can influence system performance, necessitating climate-controlled structures that further increase operational costs. Economic feasibility therefore depends on crop selection, scale of operation and market linkage for high-value seed or planting material.

CONCLUSION

Aeroponic technology represents a transformative approach to sustainable, high-quality seed production in vegetable crops. Its ability to deliver pathogen-free, physiologically superior and genetically pure seeds under controlled environments makes it a cornerstone of modern agronomic innovation. Although initial costs and

technical challenges exist, continuous research, technological innovation and institutional support are making aeroponics increasingly accessible.

REFERENCES

- Martinez-Nolasco C, Padilla-Medina J A, Nolasco J J M, Barranco-Gutiérrez A I, Prado-Olivarez J and Santoyo-Mora M. 2023. Validation of Aeroponic Cultivation of Jalapeño Pepper (*Capsicum annuum* L.) through Thermal and Morphometric Characterization of Roots and Leaves.
- Jamshidi A R, Ghazanfari Moghaddam A and Mozafari Ghoraba F. 2020. Simultaneous optimization of water usage efficiency and yield of cucumber planted in a columnar aeroponic system. *International Journal of Horticultural Science and Technology* 7(4): 365-375.
- Del Valle-Echevarria A R, Kantar M B, Branca J, Moore S, Frederiksen M K, Hagen L, ... and Baumler D J. 2019. Aeroponic cloning of *Capsicum* spp. *Horticulturae* 5(2): 30.
- Sadawarti M J, Singh S P, Buckseth T, Singh R K, Samadhiya R K, Katare S, ... and Singh B. 2023. Evaluation of aeroponic minituber's potential for basic seed production. *Potato Journal* 50(2): 185-188.
- Rajatha K D, Prasad S R, Gobhinath P S R, Nethra N and Thimmegowda M N. 2022. Soilless system: An approach for hybrid seed production in tomato (*Solanum lycopersicum*). *The Indian Journal of Agricultural Sciences* 92(9): 1107-1112.
- Chandra S, Khan S, Avula B, Lata H, Yang M H, ElSohly M A and Khan I A. 2014. Assessment of total phenolic and flavonoid content, antioxidant properties, and yield of aeroponically and conventionally grown leafy vegetables and fruit crops: A comparative study. *Evidence-Based Complementary and Alternative Medicine* 2014(1): 253875.