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Disease-Free Seed Systems through Aeroponics and Hydroponic Technology

[1]Shaurya Parganiha, [2]Hem Prakash Verma, [3]Sweta Parganiha and [4]Jitendra Trivedi

[1]PhD Scholar, Department of Vegetable Science, College of Agriculture, IGKV, Raipur (C.G.)

[2]Senior Research Fellow, ICAR-National Institute of Biotic Stress Management, Baronda, Raipur (C.G.)

[3]PhD Scholar, Department of Soil Science, College of Agriculture, IGKV, Raipur (C.G.)

[4]Principal Scientist, Department of Vegetable Science, College of Agriculture, IGKV, Raipur (C.G.)

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Abstract

The increasing demand for high-quality and disease-free planting material has accelerated the adoption of advanced soilless propagation technologies in modern agriculture. Aeroponics and hydroponics have emerged as efficient and sustainable approaches for seed production, particularly in potato, where seed degeneration due to pathogens and viral accumulation significantly affects productivity. These systems provide controlled environments that minimize soil-borne diseases, enhance nutrient use efficiency and enable rapid multiplication of planting material. Aeroponic systems facilitate high mini-tuber production with improved uniformity, while hydroponics supports vigorous seedling growth with substantial water savings. The integration of tissue culture with these technologies further strengthens pre-basic seed production by ensuring genetic purity and reducing degeneration cycles. In addition, these systems offer advantages in terms of economic feasibility, climate resilience, and resource-use efficiency. However, their large-scale adoption depends on addressing challenges related to initial investment, technical expertise, and infrastructure. With appropriate policy support, capacity building, and institutional linkages, aeroponic and hydroponic technologies hold significant potential to enhance seed systems, improve productivity, and promote sustainable and climate-resilient agriculture.

Keywords: Aeroponics, Hydroponics, Disease-free seed, Potato and Tissue culture.

Introduction

Seed quality is one of the most critical factors determining crop productivity and sustainability (Food and Agriculture Organization, 2019). Conventional soil-based seed

production systems are often constrained by soil-borne diseases, pest infestation, poor nutrient management, and low multiplication rates. These limitations are particularly severe in potato, where degeneration caused by viral accumulation significantly reduces yield over successive generations (Buckseth *et al*., 2016; Khurana, 2017). To overcome these challenges, soil-less cultivation systems such as aeroponics and hydroponics have gained prominence. These technologies provide controlled, pathogen-free environments that facilitate rapid plant growth and efficient seed multiplication. Research institutions and seed enterprises increasingly adopt these systems to meet the growing demand for certified, disease-free planting material (Otazu, 2010).

Seed Degeneration in Traditional Systems

In conventional field-based seed production, soil-borne pathogens such as *Rhizoctonia solani*, *Fusarium* spp., and *Phytophthora* spp. severely compromise seed health and quality (Khurana, 2017). Additionally, viral infections accumulate progressively across field generations, leading to seed degeneration and yield decline (Buckseth *et al*., 2016). Traditional seed multiplication generally requires five to seven field generations, which increases exposure to pests and diseases and ultimately raises production costs (Otazu, 2010). The low seed replacement rate further limits farmer access to certified, high-quality seed.

Aeroponic Technology

Aeroponics is an advanced soil-less cultivation technique in which plant roots are suspended in air and intermittently misted with nutrient solutions. This system eliminates soil contact, thereby drastically reducing disease exposure and ensuring near-zero soil-borne pathogen incidence (Sharma & Singh, 2020). High oxygen availability around the root zone enhances root respiration and nutrient uptake, accelerating plant growth and development. For seed production, aeroponics offers remarkably high multiplication rates, producing 20 to 40 mini-tubers per plant under optimized conditions (Buckseth *et al*., 2016). The system allows uniform nutrient delivery and efficient space utilization, making it suitable for commercial-scale seed farms. Moreover, reduced crop cycles enable multiple generations within a year, thereby shortening the seed production chain (Otazu, 2010). Countries such as Kenya have successfully implemented aeroponic technology for potato seed production, significantly enhancing seed availability (Mbiyu *et al*., 2012). In India, large-scale adoption by research organizations and seed corporations has further strengthened pre-basic seed systems.

Hydroponic Technology

Hydroponics involves growing plants in nutrient-enriched water solutions without soil. This system enhances nutrient uptake efficiency and promotes faster vegetative growth under controlled greenhouse conditions (Calori *et al*., 2017). Hydroponic systems are highly water-efficient, using up to 80-90 per cent less water compared to conventional field cultivation (Food and Agriculture Organization, 2019). The controlled environment reduces weed incidence and pest pressure, ensuring healthier seedlings with lower mortality rates (Singh & Pandey, 2019). Hydroponics is particularly suitable for greenhouse-based seedling and plug production, producing uniform and robust planting material. Under protected conditions, it also supports virus-free propagation when combined with strict sanitary measures.

Economic Feasibility and Scalability

The economic viability of aeroponic and hydroponic seed production systems is a critical factor influencing their large-scale adoption. Although the initial capital investment for infrastructure, climate control systems, and skilled labor is relatively high, the long-term benefits in terms of enhanced multiplication rates, reduced disease incidence, and improved seed quality often outweigh the costs. Studies have indicated that aeroponic systems can significantly reduce the number of field generations required, thereby lowering cumulative production expenses and minimizing yield losses associated with seed degeneration (Otazu, 2010; Buckseth *et al.,* 2016). Moreover, higher output per unit area and faster turnover cycles contribute to increased profitability. With appropriate financial support mechanisms such as subsidies, credit facilities, and public–private partnerships, these technologies can be made accessible to progressive farmers, start-ups, and seed enterprises, thereby improving scalability and commercialization potential (Food and Agriculture Organization, 2019).

Climate Resilience and Resource Use Efficiency

Aeroponics and hydroponics offer significant advantages under changing climatic conditions and increasing resource constraints. These systems operate in controlled environments, reducing exposure to abiotic stresses such as drought, temperature variability, and soil degradation. Hydroponic systems are highly water-efficient, utilizing up to 80–90% less water compared to conventional farming systems (Food and Agriculture Organization, 2019). Additionally, precise nutrient delivery minimizes fertilizer losses and environmental pollution, while aeroponic systems

improve root aeration and nutrient uptake efficiency, resulting in faster plant growth and higher productivity (Sharma & Singh, 2020; Singh & Pandey, 2019). These attributes make soilless cultivation technologies highly suitable for sustainable and climate-resilient agriculture.

Integration with Tissue Culture

The integration of tissue culture with aeroponics and hydroponics has revolutionized pre-basic seed production systems. Disease-free plantlets produced through tissue culture serve as Generation 0 (G_0) material, which is subsequently multiplied in aeroponic systems to produce Generation 1 (G_1) mini-tubers. These are then used for further field multiplication to generate certified seed in G_2 and G_3 generations (Pruski, 2015; Indian Council of Agricultural Research, 2022). This integrated approach significantly reduces degeneration cycles and enhances genetic purity and seed health.

Capacity Building and Institutional Support

The successful adoption of aeroponic and hydroponic technologies depends on adequate technical knowledge, infrastructure, and institutional support. Farmers and stakeholders require specialized training in nutrient management, system maintenance, and disease monitoring to effectively manage these systems. Capacity-building initiatives, including skill development programmes, demonstration units, and extension services, are essential for enhancing adoption rates (Indian Council of Agricultural Research, 2022). Research institutions and agricultural organizations play a vital role in developing standardized protocols and disseminating best practices (Pruski, 2015). Strengthening collaboration between research institutions, government agencies, and the private sector can further accelerate technology dissemination and ensure quality seed production systems.

Conclusion

Aeroponic and hydroponic technologies represent transformative innovations in the domain of disease-free seed production, particularly for crops such as potato where seed degeneration remains a persistent constraint. By providing controlled, soil-less environments, these systems effectively minimize pathogen load, enhance nutrient use efficiency, and enable rapid multiplication of high-quality planting material. The integration of tissue culture with aeroponic and hydroponic systems further strengthens the seed production chain by ensuring genetic purity and reducing the number of field generations required, thereby improving overall

system efficiency. Beyond their technical advantages, these technologies demonstrate strong potential in terms of economic viability, resource-use efficiency, and climate resilience. Higher productivity per unit area, reduced crop cycles, and efficient utilization of water and nutrients contribute to improved profitability and sustainability. However, the widespread adoption of these systems is contingent upon addressing challenges related to initial investment, technical expertise, and infrastructure availability. Therefore, a comprehensive approach involving policy support, capacity building, institutional strengthening, and public–private partnerships is essential to scale up these technologies. Strategic investments in research, training, and extension services will play a crucial role in facilitating technology dissemination and adoption. Overall, aeroponic and hydroponic seed production systems offer a viable pathway towards strengthening seed security, enhancing agricultural productivity, and promoting sustainable and climate-resilient farming systems.

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