AATCC Review

13 October 2024: Received
15 December 2024: Revised
16 January 2025: Accepted
21 January 2025: Available Online

https://aatcc.peerjournals.net/

Original Research Article

Open Access

Review on aeroponics based potato seed production for food security and sustainable agriculture

Madhurjit Singh Rathore[1], Akash Mahakul[1], Kshitij Tiwari[1], Rahul Prajapati[1], Nimisha Maheshwari[1], Ravi Yadav[1], Narendra Vasure[1], Sushma Tiwari[1]* and Y. P. Singh[2]*

[1]*Biotechnology Centre, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh, India, 474011*
[2]*Directorate of Extension Services, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh, India, 474011*

ABSTRACT

Potato (Solanum tuberosum L), a vital food crop in the Solanaceae family, has its origins in Peru's Inca regions. The traditional method of utilizing the harvest from the previous season as seed tubers frequently results in the accumulation of seed borne diseases, which causes seed degeneration and large production losses. Aeroponics, in particular, is noted for its advantages in growing plants in a misted nutrient medium, free from soil or aggregate media. This technique, when combined with tissue culture's meristem culture, ensures the production of pathogen-free seed tubers by eliminating viral pathogens from the plantlets before aeroponic propagation. The integration of these methods can overcome the limitations of conventional techniques, offering year-round production and enhanced control over environmental conditions. The use of aeroponics, supplemented by tissue culture, provides a robust solution to the challenges faced in traditional potato seed production. It facilitates the rapid multiplication of healthy, high-quality seed tubers, crucial for maintaining genetic diversity and improving crop yields. This approach is particularly beneficial for developing countries, where resource constraints often limit the effectiveness of conventional methods. There is need to compile aeroponics overview to understand the significance and limitations of the potato seed production through aeroponics for global food security. This review underscores the importance of adopting aeroponics and tissue culture to enhance potato seed propagation and ensure sustainable agricultural practices.

Keywords: *Aeroponics, food security, Mini tubers, Potato seed production, Status and prospects of aeroponics, sustainable agriculture, Tissue culture-based potato production*

Introduction

Potato (*Solanum tuberosum* L.), a member of the Solanaceae family, is one of the most important agricultural crops grown worldwide. Tetraploid (2n = 4x = 48) potatoes are the most widely produced kind; however, diploid (2n = 2x = 24) and pentaploid (2n = 5x = 60) potatoes are also available. Sustainable agricultural improvements are among the most important criteria for ensuring global food security and climate-smart agriculture. The increasing global population is driving higher demand for food, making it difficult to ensure a sufficient supply of nutritious options. Potatoes, due to their high nutritional value, have become a key solution. With exceptional yield potential, adaptability to various climates, and a rich nutrient profile, potatoes are now recognized as a leading staple crop worldwide. They surpass cereals in protein production per hectare and provide superior dry matter content, highlighting their importance in global food security. Moreover, the potato possesses the highest biological grade protein. It has the capacity to play a crucial role in filling the gap in global food security. Potatoes serve not only as a staple food but also as a cultivated vegetable for consumption. Additionally, they are processed into various products such as French fries, chips, frozen goods, dry goods, and starch for manufacturing purposes. India is now the world's second-largest producer of potatoes, behind China, as global production has increased from 1.3 million tonnes to over 34 million tonnes in the last 60 years, with 56 million metric tons produced [1]. However, a number of less obvious trends in the growth rates for potato yields, area, and output are hidden by this astounding increase.

In India, Utter Pradesh ranks 1st with a production share of 29.65%, followed by West Bengal (23.51%), Bihar (17.02), Gujrat (7.05), and Madhya Pradesh ranks 5th with a production share of 6.68% [2]. Two tons of tubers, each with an average size of 50 g, are needed for every hectare of potatoes. The average tuber size in the polyploid series (2n = 2x = 24 to 2n = 6x = 72) is mostly determined by the genetic resources of the potato, facilitating gene transfer across ploidy levels. Among these, primary commercial potato varieties are classified into two groups: tuberosum (TBR) and andigena (ADG). Currently, there are several potato propagation methods utilized all over the world to increase the amount of seed potatoes. Nonetheless, the majority of farmers in developing nations multiply potato seeds by utilizing the traditional technique for producing seed tubers. All techniques have their drawbacks and difficulties, but when it comes to generating high-quality seed tubers for farmers with limited resources, the conventional technique has the most obstacles. The standard method of producing potato seed has not proven successful in preventing or minimizing the spread of diseases. This is mostly because of the fact that most farmed potatoes are outbred, vegetatively propagated autotetraploids that are susceptible to several seed-borne diseases that cause the degradation of seed stocks over time.

*Corresponding Author: ***Sushma Tiwari and Y. P. Singh***

DOI: https://doi.org/10.21276/AATCCReview.2025.13.01.20

Farmers also use the crop from the previous season as seed tubers. Disease concerns like late blight, early blight, common scab, soft rot, fusarium wilt, potato pink rot are predominated when it comes to maintaining vegetative supplies. As a result of seed degradation, yield and tuber quality are significantly lost. Thus, using high-quality seed is essential for profitable cultivation. Today, a number of methods for producing seeds are employed all over the world, including aeroponics, hydroponics, and tissue culture. Because aeroponics is thought to have several benefits over these other strategies, early experimental tests have demonstrated that it is one of the most successful techniques among them [3].

Aeroponics refers to the cultivation of plants in a controlled habitat that relies only on air or mist and does not employ soil or any other solid media. The Latin terms "aero" (air) and "ponic" (effort) are the roots of the English word "aeroponic" [4]. In this system, plants are grown by suspending their roots in a misted nutrient solution. Meristem culture is a key technique for eliminating viral infections from potato varieties, ensuring the production of clean seed tubers. In this study, meristem culture was used to generate pathogen-free plantlets, which were then propagated using an aeroponics system. This combination is essential because, while aeroponics allows for efficient tuber production, it does not by itself eliminate viral pathogens. Therefore, the initial step of meristem culture in tissue culture is crucial to cleanse the potato clone of viral diseases. Once clean, the aeroponics system enables the rapid and healthy development of superior seed tubers, free from pathogens, by maintaining a sterile and controlled environment [5]. Tissue culture is a collection of in vitro techniques that allow for the propagation of plants in a controlled, sterile environment. This method is crucial for maintaining the health and genetic purity of crops, especially in producing disease-free seed potatoes. In particular, meristem culture, a specific form of tissue culture, is employed to eliminate systemic viral infections from potato plants. This is because the meristem, the actively dividing tissue at the tips of shoots, often remains virus-free even when the rest of the plant is infected. By isolating and cultivating these virus-free meristematic tissues in a sterile medium, researchers can produce clean, virus-free plantlets.

Once the initial cleaning phase is complete, these virus-free plantlets are propagated in tissue culture to produce a sufficient number of clean clones. Tissue culture maintains the sterility and ensures that the plantlets remain free from contamination before they are transferred to the aeroponics system for further growth. The aeroponics system, known for its efficiency and reduced disease transmission, then provides the ideal environment for tuberization, allowing the pathogen-free plantlets to develop into healthy seed tubers. However, the effectiveness of the aeroponic system alone is limited if the plant material is not initially virus-free. This is why the integration of meristem culture at the start of the process is crucial, it ensures that the potato clones entering the aeroponics system are already cleaned of any viral infections. The combination of meristem culture to clean the plants and tissue culture to maintain and propagate them ensures a high standard of disease-free potato seed production, resulting in reliable and high-quality yields for farmers.

Techniques for potato breeding

Seed potatoes are multiplied using various methods worldwide, such as traditional seed potato production, hydroponics, aeroponics, and micropropagation. In developing countries, many farmers rely primarily on the conventional method to produce seed tubers. Although each method has its own limitations and challenges, the conventional approach faces significant constraints, particularly for the purpose of growing superior seed tubers in situations with limited resources (Figure 1).

Conventional method for potato production

The traditional technique for producing seed potatoes involves replanting of the tubers that were previously harvested. "Seed potatoes" generally refers to the tubers which are used for planting. The purpose of seed potatoes is that farmers need to select superior quality tubers and discard the inferior ones. The process of identifying and segregating healthy and diseased plants is carried out, and in the next season, only the healthy tubers are used for production. Potatoes and other crops grown vegetatively are prone to bacterial and viral diseases. The accumulation of diseases brought on by the conventional method of growing seed potatoes eventually lowers crop output [6]. When a mother plant is infected with a particular disease during the growing season, there is a variable risk that the daughter tubers will also be infected. The likelihood of transmission to daughter tubers depends on the type of pathogen and the stage of infection in the mother plant. For example, viruses like Potato Virus Y (PVY) and Potato Leafroll Virus (PLRV) have a high transmission rate, leading to a greater chance that daughter tubers will be infected if the mother plant is diseased. In such cases, nearly all daughter tubers may show symptoms due to the systemic nature of these viruses. However, for bacterial diseases such as *Ralstonia solanacearum*, which causes bacterial wilt, the infection can be uneven. Some daughter tubers may become infected, while others may remain healthy, depending on factors like the timing of the infection and environmental conditions. Fungal diseases, like early blight (*Alternaria solani*), may not result in 100% infection of daughter tubers either, as the spores may not always reach every tuber. Therefore, infection can vary from tuber to tuber.

Furthermore, the visual inspection of fields is not always a reliable method for detecting all diseases. Not all diseases display clear or early visible symptoms, especially in the initial stages of infection. Latent infections, where the disease is present but not visibly apparent, can be particularly challenging. For instance, Potato Cyst Nematode (PCN) and latent viral infections often go undetected during routine field inspections because they do not cause immediate, noticeable symptoms on the plant. Such infections can only be detected through molecular diagnostic tools, highlighting the limitations of relying solely on visual checks.

As the number of generations increases, the likelihood of accumulating undetected infections also rises, significantly reducing the quality of seed potatoes over time. This underscores the necessity of integrating both visual inspections and advanced diagnostic techniques, such as ELISA (Enzyme-Linked Immunosorbent Assay) or PCR (Polymerase Chain Reaction), to detect latent infections that would otherwise compromise seed quality over successive generations. Seed producers need to adopt these diagnostic methods to ensure the production of healthy, high-quality seed potatoes, minimizing the risk of disease transmission from mother plants to daughter tubers."

The traditional method of seed multiplication is slowest as compared to aeroponics. In addition, this approach has demonstrated its temporal sensitivity, particularly in areas where potatoes are cultivated as a winter crop, such as tropical and sub-tropical countries. Moreover, this approach necessitates expansive land tracts for the purpose of commercial seed production. This is also linked to higher labour expenses for overseeing these large land holdings (Figure 2).

Tissue culture technique for potato plants production

It involves the growing of an explant usually plant cells, tissues or organs on an artificial nutrient media, employing sterile containers, liquid, semi-solid, or solid growth media are utilized under an aseptic environment. This technique has emerged as a crucial tool for expanding plant populations, facilitating the large-scale cultivation of potato plants within a brief timeframe. Tissue culture facilitates a flexible and expedited process of plant multiplication, resulting in a higher multiplicity rate. Meristem culture has been extensively employed for the generation of plants that are free from viruses [5, 6]. In meristem culture, the apical or axillary tips (0.1 to 0.3 mm) are dissected and cultured on a nutrient media. This approach leverages the fact that viruses are unable to infect these active growth regions, thereby enabling the generation of healthy and virus-free plants from a little fragment of meristematic tissue [7]. The apical meristem lacks a well-developed vascular system, besides high auxin content, chromosome activity during mitosis and the presence of a virus-inactivating system makes it free from virus infection. Also, meristem culture has proved to be a valuable tool in preserving the genetic makeup of plants, as the cells in meristems tend to maintain their genetic stability. Once the plant components have been rendered free of diseases, they are easily replicated for application in gardening. In nations like Vietnam, tissue culture has completely changed the way that seed potatoes are produced. This approach is widely used to efficiently propagate many plant species by micro-propagation [8]. Despite the multiple advantages, the use of potato seed multiplication has been limited especially in developing countries. The high operational costs associated with tissue culture, including the need for specialized and expensive equipment, as well as the outlays for media formulation such as nutrients, vitamins, energy sources and growth regulators, act as significant barriers [9]. In addition to this tissue culture techniques demands specialised skill and expertise that can be acquired only through formal training. Over the last twenty years, numerous Universities and National Agricultural Research organizations have created plant tissue culture labs. Nevertheless, these resources have not been extensively exploited beyond their use for undergraduate and postgraduate teaching and training, with only limited practical implementations. Tissue culture propagation is only effective when it can move plants from a germ-free environment to a non-sterile one., while ensuring a high percentage of survival and minimum costs to be commercially viable. Also, tissue-cultured plants have minimal wax on their surfaces, which is necessary for preventing water loss and protecting against diseases. Transferring these micro-propagated plants can provide difficulties because of their heightened vulnerability to transplant shock and increased susceptibility to wilting, pest infestations, and disease outbreaks upon relocation to outdoor environments. Therefore, micro-propagated plantlets need to undergo hardening, which allows them to adapt to the field conditions before they can be planted in the field or aeroponics unit [10]. Although the consistent utilization of tissue culture for seed potato production may incur high costs, this method can be successfully utilized to eradicate pathogens, generate initial material, and subsequently shift to a more efficient and cost-effective system for the rapid production of superior seed tubers for commercial purposes.

Aeroponics Technique's Potential

As its name indicates, aeroponics is a method of cultivating crops in a mist or air environment. It doesn't need soil or any other kind of aggregate material. The term "aeroponics" comes from the Latin words "aero," which means air, and "ponic," which implies labor [4]. This technique. This method provides a regulated environment for plant development as an alternative to conventional soil-based farming. Aeroponics benefits are said to be a secure and environmentally responsible way to grow organic, wholesome plants and harvests, particularly in the context of potato cultivation. This system offers several advantages over other seed potato multiplication methods, such as conventional seed production and hydroponics. Aeroponics presents a variety of advantages that make it an increasingly popular method in modern agriculture. One of the most significant benefits is its efficient use of water, consuming up to 90% less compared to traditional soil-based farming, which is crucial in regions facing water scarcity. This water-saving feature is complemented by faster plant growth; because nutrients and oxygen are delivered directly to the root zone, crops tend to have accelerated development, leading to shorter growing cycles and potentially higher yields. In addition, the lack of soil reduces exposure to soil-borne diseases, allowing for more effective disease management. Infected plants can be swiftly isolated and removed without impacting the rest of the crop, limiting the spread of pathogens.

Aeroponics also excels in nutrient efficiency, as plants absorb nutrients more effectively, minimizing waste and reducing the need for fertilizers. This precision, coupled with the capability to stack aeroponic systems vertically, optimizes space usage, particularly in urban settings where land is limited. As a result, urban farming becomes more viable, enabling food production closer to population centers. The absence of soil in the system eliminates the need for chemical pesticides, contributing to safer, pesticide-free produce that is healthier for consumers. Additionally, aeroponics facilitates year-round cultivation in controlled environments, ensuring a steady supply of crops independent of seasonal constraints. This control over the growing environment managing humidity, light, temperature, and other factors leads to improved crop quality and greater uniformity in produce. Furthermore, since aeroponics does not rely on soil, it bypasses issues related to soil degradation and erosion, making it a more sustainable and environmentally friendly agricultural practice. This innovative approach holds promise for the future of agriculture, particularly in the face of climate change and the need for sustainable food systems. It is also less labor and time-intensive than these traditional methods, which is reportedly more efficient [11]. Because the system recirculates the nutrient solution, it uses less energy and water per unit of growing area [4]. This makes the system more energy- and water-efficient. In addition, aeroponics stimulates the growth and development of roots, improves the rates of survival and growth, and shortens the time it takes for plants to mature [12]. Research findings demonstrate that aeroponics consistently outperforms conventional methods in terms of average tuber yield [13, 14], demonstrating its effectiveness in the propagation of potatoes. By hanging the plant roots entirely in the air, the technique guarantees ideal root aeration. This leads to improved root growth since the roots can absorb all of the available oxygen.

In addition, compared to plants cultivated hydroponically, plants in this aeroponic environment have access to carbon dioxide levels ranging from 450 to 780 ppm, which promotes faster development and better nutrient absorption [15, 16]. According to studies [17], the aeroponics method increased the photochemical efficiency of leaves, increased intercellular CO_2 concentration and net photosynthetic rate, and improved stomatal conductance. Additionally, aeroponics is regarded as one of the fastest techniques for seed multiplication. As per data reported, a single potato plant in an aeroponics setup can yield over 100 mini tubers in a single row, which is significantly higher than daughter tubers produced annually through other methods such as Bark, Nutrient film technique, deep flow in the study [18, 11], found that each plant produced an average of 5-6 tubers when grown in soil within a greenhouse for a period of 90 days. Aeroponics also offers a convenient way to monitor nutrient levels and pH. The technique guarantees accurate nutrient allocation for the crop, hence minimizing fertilizer consumption and decreasing the likelihood of excessive fertilizer residue also contaminating groundwater [19]. It also facilitates the measurement of nutrient uptake over different timeframes and environments. An aeroponic system employed to accurately measure the rates of water and ion absorption in cranberries without causing any damage [20]. The finding revealed that aeroponics is a valuable technique required to track down nutrient uptake, monitor plant health, and maximize crop growth under controlled environments. Aeroponics brings with it the added advantage of efficient space utilization. In comparison to other methods like hydroponics and traditional systems, aeroponics effectively utilizes vertical space, which benefits the growth and development of roots and tubers. Countries like America, Singapore, and Netherlands are leading in adopting this technology, driven by the need for sustainable and high-yield food production [21]. As climate change challenges traditional farming methods, aeroponics offers a promising alternative for the future of agriculture. In the aeroponics system, the traditional methods of pest/disease control are not applicable thus modern disease control should be developed. Based on weather and field production conditions, the best plant production period should be determined for each plant. The artificial lighting could be used to grow the plant [22].

Overview of potato aeroponics

The Aeroponics technique has been devised to produce mini tubers by using disease-free plants grown in a laboratory setting [23]. This technology enables the production of potatoes year-round and the implementation of regulated standards [24]. This approach involves planting in vitro microplants on the surface of the growing chamber, and then fogging the root zone within the chamber with a nutritional solution [25]. The aeroponic chamber has a detachable aperture in its upper part, equipped with wells designed to accommodate the potato plants. Small tuber harvesting starts 45 to 50 days after planting, depending on the potato type when the tubers are around 3-10g in size [26]. An individual in vitro plant typically yields 40 to 50 mini tubers, which may be kept at temperatures ranging from 2 to 4°C. If this technology can be integrated into the seed production process utilizing regular operating strategies to guarantee seed health and purity, it has immense potential.

National and Global Scenario of Potato Aeroponics

The current agricultural system heavily relies on rapid crop production technologies and is extensively applicable in agriculture. Previous commercial use of an aeroponics system in China and Korea resulted in the production of high-quality potato seeds [27]. Globally, aeroponics is being utilized for potato growing in various regions such as South America, Kenya, Australia, South Korea, Netherlands, Spain, Poland, Serbia, Turkey, Indonesia, and others (Table 1). In India, aeroponics is becoming a viable remedy to tackle the obstacles of conventional agriculture, including restricted cultivable areas and water shortage. The technique is being investigated in metropolitan regions and by pioneering enterprises to enhance agricultural productivity and minimize resource usage. Aeroponics in India, although still in its nascent phase, has the capacity to facilitate sustainable agricultural expansion, particularly as the nation strives to satisfy the needs of an expanding population. However, it provides superior seeds and has completely transformed seed potato processing in India [28, 23] (Table 2). An investigation by Tiwari et al. [29] has also shown variations in root form and yield characteristics among all Indian potato cultivars grown under aeroponics. This approach necessitates a significant degree of expertise in the areas of planning, operating costs, and standardization of genotype-responsive nutrition solutions.

Limitations of Aeroponics based potato production

An inherent drawback of aeroponics is the issue pertaining to the size of the water droplets [30]. Tiny droplets encourage the excessive growth of root hair without the establishment of a lateral root system, which is essential for sustained plant growth. While large droplets restrict the oxygen availability to the root system. The system also needs a steady power source for the duration of the growth season. If there is a lengthy power outage that affects the water pumps, it might lead to permanent harm to the plants. In addition, the system necessitates several maintenance procedures, during plant growth from sowing to harvest time, the methods adopted in the aeroponic system require a little hand-operated contribution, interference regarding physical presence, and expertise in domain knowledge of plants, environment control, and operations to maintain and control the growth of the plant. Moreover, there is a requirement to sustain and retain the nutrient solution parameters which include nutrient temperature, pH, and EC concentration in a narrow range of preferred values for optimal growth. If these parameters drift outside the desired range, it will create several problems for plant growth. In addition, some supplemental parameters can adjust to optimize the plant growth further. The additional parameters are atomization time, atomization interval time, air temperature, relative humidity, light intensity, and carbon dioxide (CO_2) concentration which make the system complicated and time-consuming with high human energy and with a higher level of expert training and skill for operating the system.

Future Scope of aeroponics

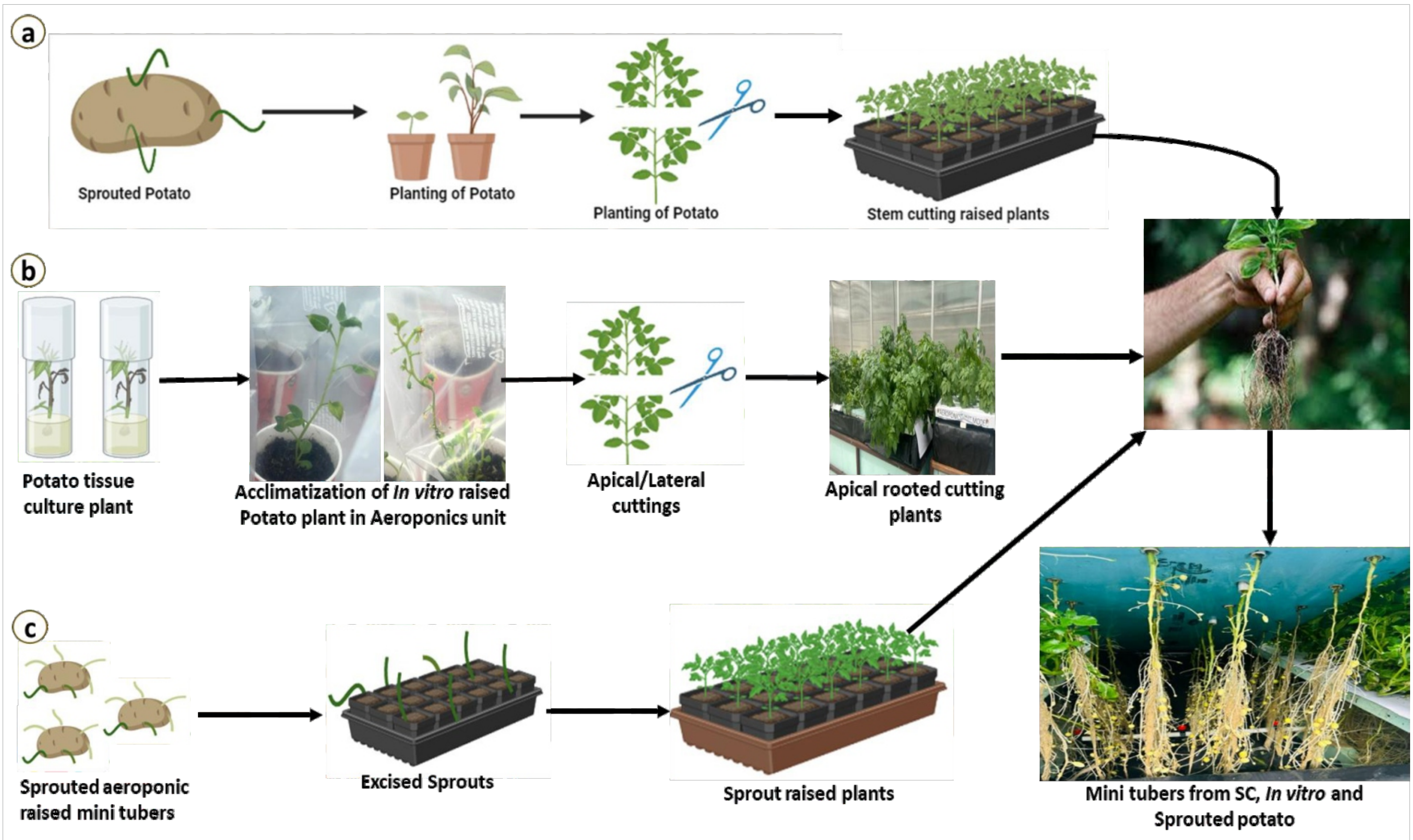
Aeroponics offers numerous advantages, including rapid seed production, improved plantlet development, and survival rate, constant air circulation, an eco-friendly strategy, and an effective nutrient monitoring system, hence promoting sustainable agriculture. These features make it an ideal solution to transform the potato seed industry, potentially increasing income and reducing the time and costs involved with generating superior seed potatoes, increasing their availability for farmers in developing nations, particularly for food security. Aeroponics has the potential to produce disease-free potato mini tubers in less time and in cost-effective manner.

It can effectively be used by farmers to increase their income and participate in global food security.

Conflict of interest: Authors declare no conflict of interest

Acknowledgements: Authors are thankful to MANDI Board, Bhopal, India for providing financial support for Aeroponics based potato seed production.

Authors contribution: MSR: Written first draft, figs and tables; AM: first draft, table; KT: editing, table formation; RP: revision, formatting; NM: corrections, formatting; NV: literature collection, compilation; RY: corrections, revision and ST: outline, drafting; YPS: concept of review, revision.



production. (a) Stem cuttings (SC), (b) In vitro plants and (c) Sprouts (from previous season minitubers)

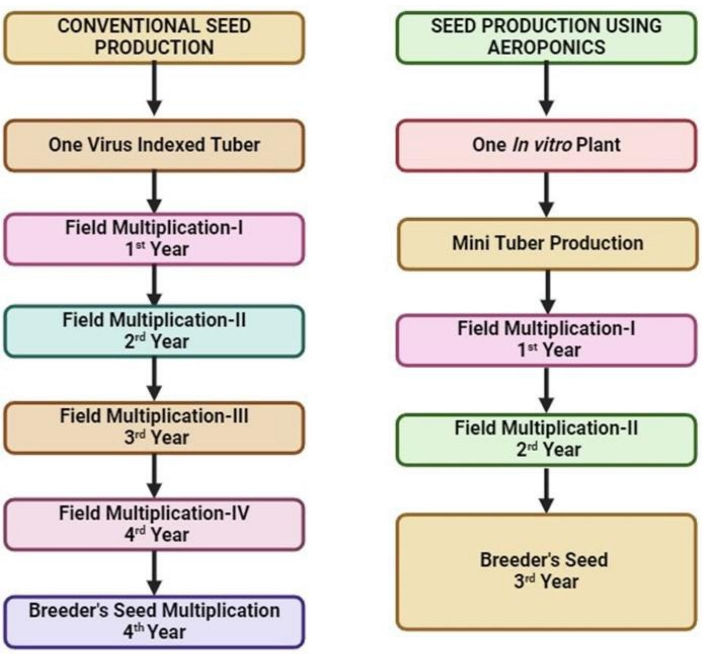


Figure. 2. Comparison of conventional and aeropnics seed potato production system.

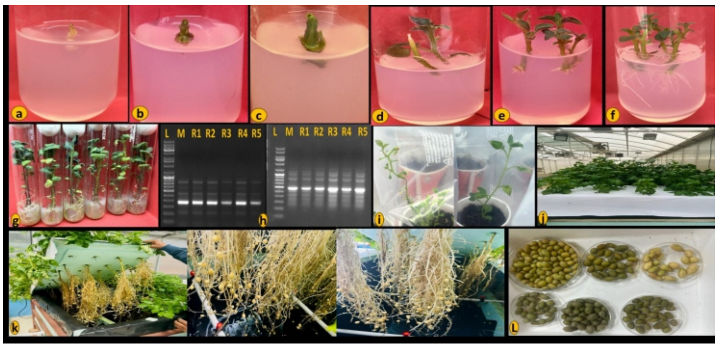


Figure 3. *In vitro* micropropagation of Potato (*Solanum tuberosum*) and *in vivo* apical root cutting and mini-tuber production through aeroponics (a) *In vitro* establishment from initial sprout explant, (b) Shoot initiation, (c) Shoot proliferation, (d) Transfer of shoot on multiplication medium, (e) Transfer of multiplied shoot to rooting medium and root initiation, (f) Rooted shoots, (g) Completely rooted plants ready for field transfer, (h) Genetic stability testing of *in vitro* raised plants through SCoT molecular markers, (i) Primary hardening of *in vitro* raised plants, (j) Thirty days growth in aeroponics, (k) Potato mini-tubers formation in the aeroponic system and (L) yield of mini-tubers in the aeroponics unit.

Table 1. Global status of aeroponics potato cultivation: a broad overview across different regions

Sr. no	Countries	Work done	Institution	Varieties/cultivar	Results/yield attributing characters	Remarks	References
1	Serbia	Potato Aeroponics: Effects of cultivar and plant Origin on minituber production	RZ Plant & Potato, Research Center Guca, Serbia	Agria, Cleopatra, Désirée, Kennebec, and Sinora	Sinora: 7.17kg/m2	An earlier transfer to the aeroponic system, short harvest intervals and use of acclimated micro plants as a starting material promoted minituber production and increased the yield of Agria and Kennebec, but not the other investigated cultivars.	[34]
2	Turkey	Comparison of aeroponics and conventional potato minituber production systems at different plant densities.	Nigde Omer, Halisdemir University, Nigde, Turkey	Hermes, Sante and Marabel (1st cycle), Hermes and Sante (2nd cycle)	Aeroponics system: 5.9–9.3 kg/m2, Conventional system: 3.4–3.5 kg/m2. In the 2nd cycle, cultivar Sante had a much higher yield than cultivar Hermes in the aeroponics system.	An increase in tuber yield per m^2 was observed with increased plant density but mean tuber weight decreased simultaneously. Tuber yield per m2 was lowest at 25 plants/m2 and highest at 200 plants/m2 for both cycles and both systems. In the 2nd cycle, cultivar Sante had a much higher yield than cultivar Hermes in the aeroponics system.	[13]
3	Netherlands	Improved Production of High-Quality Potato Seeds in Aeroponics with Plant-Growth-Promoting Rhizobacteria	All- Russia Research Institute of Agricultural biotechnology, Moscow	Nevsky, Kondor	Nevsky : 7.99kg/m2 Kondor: 7.39kg/m2	Bacterium A. brasilense Sp245 improves the quality of minitubers, as well as the growth, development and yield performance of potato plants	[35]
4	Indonesia	Effect of electrical conductivity (EC) in the nutrition solution on aeroponic potato seed production with root zone cooling application in tropical lowland, Indonesia	Faculty of Agriculture, Jenderal, Soedirman University, Purwokerto, Indonesia.	Granola	-	The higher EC (EC3) indicates a less healthy root condition than EC1 and EC2 and tuber yield	[36]
5	Brazil	Seed potato minituber production in an aeroponic system under tropical conditions: electrical conductivity and plant density	Agencia Paulista de Tecnologia dos Agronegocios (APTA – Sao Paulo's Agency for Agribusiness Technology	Agata and Asterix Granola	Agata: 994 minitubers/m2 Asterix: 790 minitubers/m2	The best EC values under our experimental conditions (autumn/winter) were 2.1 and 1.7 dS m-1 for "Agata" and "Asterix", respectively	[37]
6	Romania	Previous results on obtaining minitubers by aeroponic method applied at National Institute of Research and Development for Potato and Sugar Beet. Brasov	National Institute of Research and Development for Potato and Sugar Beet Brasov	Brasovia, Castrum, Marvis,Sarmis	Castrum: 6.25 minitubers/plant Marvis: 5.25 minitubers/plant Sarmis: 4 minitubers/plant Brasovia: 3.38 minitubers/plant	Using of aeroponic system with 16 plant density system has a positive influence on minitubers number (with a significant positive difference 0.66 minitubers).	[38]
7	Poland	The potato minituber production from microtubers in aeroponic culture	Plant Breeding and Acclimatization Institute – National Research Institute, Jadwisin, Poland	Ametyst and Tajfun	Ametyst: 13.89kg/m2 Tajfun: 11.73kg/m2	Number of minitubers was two to three times greater in the case of aeroponic production than by traditional method.	[39]
8	Iran	The impact of aeration on potato (*Solanum tuberosum* L.) minituber production under soilless conditions	Horticulture Science Department in Ferdowsi University of Mashhad, Iran	Agria and Sante	Agria: 3793 minitubers/m2 Sante: 3781 minitubers /m2	Aerated plants had (a) more dry matter in their haulms because of more leaves and shoots, (b) larger leaf areas, and (c) delay in physiological maturity. Higher levels of tuber growth, longer roots and more stolons led to improvements in root: shoot ratio. Leaf area index duration increased remarkably by increased aeration.	[40]

9	Canada	A low nutrient solution temperature and the application of stress treatments increase potato mini-tubers production in an aeroponic system	Laval University, Quebec, Canada	Chieftain, Mystere	Under N (-) condition Mystere: 48 minitubers/plant Chieftain:72 minitubers/plant		Plants subjected to nitrogen withdrawal at tuberization [N (−)] exhibited faster tuberization, higher mini-tuber number but lower tuber weight and were characterized as well by a significant higher root length, stolon number/plant and number of stolon branches/ plant	[41]
10	Kenya	Up-scaling production of certified potato seed tubers in	Agricultural Research Institute (KARI), Tigoni	Asante and Tigoni	Tigoni: 112 minitubers/plant (1st season) &122 tubers/plant (2nd season)	Asante: 54 minitubers/plant (1st season) & 55 minitubers/plant (2nd season)	Aeroponics technology produced far more minituber than the conventional pot method. The aeroponics technology might offer some solution to the perennial problem of shortage of certified potato seeds in Kenya	[42]
11	South Korea	Aerohydroponic culture system for seed potato production of chipping variety 'Atlantic'	National Institute of Highland Agriculture (NIHA), RDA of Korea	Atlantic	Aerohydroponics: 342g/plant (tuber weight)		Aerohydroponics was a suitable alternative for seed potato production, particularly for late maturing variety 'Atlantic'.	[43]
12	Spain	Comparison of hydroponic and aeroponic cultivation systems for the production of potato minitubers	Instituto Vasco de Investigacion y Desarrollo Agrario, Apartado 46, 01080 Vitoria Gasteiz, Spain	Nagore	Hydroponics: 65.3g/plant, Aeroponics:109.9g/ plant production in hydroponics, the tuber yield per plant in the aeroponic system was almost 70%		higher and tuber number more than 2.5-fold higher. Average tuber weight was reduced by 33% in the aeroponic system.	[3]
13	Australia	Aeroponics: a novel technology for seed potato production	Australian Centre for International Agricultural Research (ACIAR)	Sebago	22 t/ha		Aeroponics produces six to eight times more tubers than conventional production techniques	-

Table 2. Aeroponics potato cultivation in India: trends and developments over the years

Sr. no	**Work done**	**Varieties involved**	**Yield attributes**	**Remarks**	**References**
1	Evaluation of aeroponic minituber's potential for basic seed production	K. Chandramukhi, K. Lauvkar, K. Surya, K. Pukhraj, K. Khyati, K. Lima and K.Jyoti, K.Chipsona-1, K.Chipsona-3,K. Himalini, K. Mohan, K. Karan, K. Ganga, K. Thar.-2, K. Sangam, Kufri Neelkanth and K. Garima	Tuber yield/m² was ranged from 0.49-3.31 kg and highest was reported in K. Neelkanth (3.31Kg/m2) and lowest in K. Garima (0.49 Kg/m2)	There is significant variability among potato varieties in terms of emergence, yield attributes and Kufri Neelkanth emerged as the top-performing variety in the study, particularly in terms of yield and yield parameters	[44]
2	Influence of Micro-plant Hardening Methods on Aeroponic Potato Mini-tuber Production	Kufri Himalini, Kufri Lauvkar, Kufri Khyati and Kufri Jyoti	K. Himalini :48.58 tubers/plant K. Jyoti: 31.80 tubers /plant K. Lauvakar: 49.75 tubers/plant	Micro-plant hardening by gradually acclimatizing (1 week) them to the outer conditions was found to be the best treatment in all aspects and is recommended for harnessing the full potential of the plants for mini-tuber production through aeroponics. Since no extra hardening facilities are required, this was found to be cost-effective.	[28]
3	Influence of soil solarization on the multiplication of aeroponic seed potato under net house (Gen-0) and open field conditions (Gen-1) of north central India	Kufri Mohan, Kufri Chipsona-1 and Kufri Lauvkar	Gen-0: polythene solarization (29.33 t/ha) § solarization with paddy straw mulch (26.75 t/ha) Gen-1: unsolarized soil (26.07 t/ha). paddy straw mulch (37.45 t/ha) polythene solarization (32.45 t/ha) unsolarized soil (31.34 t/ha).	Solarization with polythene and paddy straw mulch resulted in 88.23% and 41.05% reduction in weed population under net house and 74.80 and 37.79% reduction under open field conditions. Under net house straw mulch (37.45 t/ha) over other two treatments respectively. higher with polythene solarization (29.33 t/ha), whereas, under open field conditions yield was maximum with paddy conditions, total tuber yield was significantly	[45]

4	Precision phenotyping of contrasting potato (*Solanum tuberosum* L.) varieties in a novel aeroponics system for improving nitrogen use efficiency: In search of key traits and genes	Kufri Gaurav, Kufri Jyoti	stolon surface area K. Jyoti: 0.7m2/plant (7.5 mmol L-1 NO3-) 0.5m2/plant (0.75 mmol L-1 NO3-) K. Gaurav: 1.6m2/plant (7.5 mmol L-1 NO3-), 0.8m2/plant (0.75 mmol L-1 NO3-)	Maximum stolon length and stolon surface area values were observed in Kufri Gaurav at high N and the minimum in Kufri Jyoti at low N	[26]
5	Genotypic Diversity in Aeroponics Based Mini-Tubers Production System Reveals High Photo-Assimilates Partition Capacity of Kufri Kanchan	Kufri Megha, Kufri Himalini, Kufri Girdhari and Kufri Kanchan	K. Kanchan: 1097.6 no. of mini-tuber K. Himalini : 472.4 minitubers	By considering the overall yield parameters, K. Kanchan is performing best followed by K. Himalini in aeroponics based mini-tuber production system	[45]
6	Effect of canopy management practises on growth and yield of potato in net house	Kufri Pukhraj, Kufri Gaurav and Kufri Chipsona-1,	K. pukhraj: 3.95kg/plot K. Gaurav: 5.55 kg/plot K. Chipsona 1: 3.14 kg/plot	Better management of canopy can be done by double net control system as compared to single net control	[46]
7	Performance of Sprout Cutting and Aeroponic Minituber of Potato (*Solanum tuberosum* L.) In in vivo Condition of Central India	Kufri Lauvkar	Sprout top portion: 175g minituber/plant Sprout middle portion :190g minituber/plant Sprout lower portion: 270g minituber/plant	Production potential of sprout portions is less than minitubers with seed multiplication rate in the range of 6.0—10.7, hence sprout cutting also can be inteevaluation of sprouts for viruses for increasing seed production rate	[47]
8	Effect Of Microplants hardening on aerponic potato seed production	Kufri Jyoti, Kufri Girdhari, Kufri Himalini and Kufri Lauvkar	K. Jyoti: 2.59 tubers /m²(kg), K. Girdhari :2.26 tubers/m2(kg), K. Himalini :1.65, tubers/m2(kg), K. Lauvkar :1.21 tubers/m2(kg)	For obtaining maximum number and yield of mini-tubers with ideal mini tuber seed size (>3g), the micro-plants of the studied varieties without hardening can be used in aeroponic system under Shimla conditions	[48]
9	Use of aerponics for quality seed production in north eastern Himalayan region of India	Kufri Megha, Kufri Himalini, Kufri Himsona	K. megha: 118-108g tubers/plant, K. Himalini: 162-102g tubers/plant, 138-39.25g tubers /plant	Aeroponics system can be successfully utilised for augmenting the production of tissue culture-based disease-free quality seed potato in the NE regions all the three varieties were able to produce mini-tubers. for the mini-tubers. harvesting of mini-tubers allows selection of desired size Sequential	[49]

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