Review Article

Aeroponics: Transforming Vegetable Farming for the Future

Abstract

The global population is projected to reach 9.8 billion by 2050, necessitating a 60-70% increase in agricultural production. Traditional soil-based farming faces challenges like soil degradation, water scarcity and climate vulnerability. Aeroponics, a soil-less cultivation method, offers a solution. By suspending plant roots and misting them with nutrient-rich solutions, aeroponics maximizes resource efficiency, reduces water consumption by 96% and ensures consistent yields year-round. It's particularly effective for high-value crops like potatoes and tomatoes. Despite initial costs and technical complexities, aeroponics presents a sustainable alternative for future food production, demonstrated by successful implementations worldwide, including in India and the United States.

***Keywords**: Soil-less cultivation, Aeroponics, future farming, nutrient rich solution*

Introduction

The United Nations predicts that the global population will reach 9.8 billion by the year 2050 (Anonymous, 2017). Currently, only 80% of the Earth's land is considered arable and suitable for farming. However, approximately 15% of this arable land has become unusable for agriculture due to a combination of factors including poor land management practices and the effects of climate change. Globally, just 9% of the land is suitable for crop cultivation whereas, the remaining 91% facing various stresses as well as 50% area is suffering to abiotic factors (Oerke*et al.*, 1994; Theilert, 2006). In 2021, the global vegetable cultivation area covered approximately 58.2 million hectares with total production reaching 1.17 billion metric tons. Projections indicate that global agricultural production must rise by approximately 60-70 percent from its current levels in order to fulfil the increasing demand for food by the year 2050 (Anonymous, 2017). The primary constraints of soil-based cultivation include soil degradation, water scarcity, climate vulnerability, pest and disease pressure, limited arable land, nutrient management challenges, and labour intensiveness. Currently, traditional agriculture utilizes roughly 70% of the world's freshwater resources and this trend is expected to continue by the year 2025. These factors pose significant challenges to agricultural productivity and sustainability, requiring the adoption of sustainable soil management practices. These challenges will be overcome with some strategies *viz.*,efficient water use, nutrient management, resilient crop varieties, integrated pest and disease management approaches and technological innovations to mitigate their impacts and ensure food security in the face of changing environmental and socio-economic conditions.

For future prospects, replacing soil-based cultivation entails transitioning to soilless growing methods such as hydroponics, aeroponics, and aquaponics. These methods offer controlled environments, optimized resource use,higher uptake as well as productivitypotential (Kratsch*et al.*, 2006). By eliminating soil constraints, they mitigate issues like soil degradation, water scarcity and climate vulnerability. Additionally, they reduce land requirements, alleviate nutrient management challenges and offer automation opportunities to streamline operations. However, implementation requires addressing technological, economic and regulatory barriers while ensuring sustainability and equitable access. Embracing soilless cultivation holds promise for enhancing food production, resilience and resource efficiency in the future agricultural landscape.

History

In 1920s, botanists were developed first developed those plants growing soilless medium with used primitive stage of aeroponics to studied root structure and root physiology of plant (Barker, 1922). This technology was mostly used as a research purpose rather than an economically feasible method of production. First time used misted vapour in citrus and avocado for the study of root disease by Klotz (1944). Trowel (1952) was grown apple trees in a spray culture. In 1983, first time developed commercial aeroponics setup used through microchip and electrical outlets was commonly called as a Genesis Machine. F. W. Went (1957) was coined term “aeroponics” for air growing methods as well as growing the tomato and coffee with aeroponics technique (Sharma *et al.*, 2018).

NASA reported higher biomass and production in soil-less technique during the 1990s. Lommen and Struik (1992) studied that the timing and number of the harvests were the key factors for production of mini-tuber. In korea, first time aeroponics system applied for production of potato seed tuber (Kim *et al.*, 1999). Under temperate conditions, minituber production using aeroponics techniques demonstrated by Ritter *et al.* (2001). At International Potato Centre (CIP), Farran and Mingo (2006) also worked on comparative study on minituber potato productuction in aeroponics and conventional method (Otazu, 2010). Aeroponics method of production of potato minituber was also tested in several African countries (Lungaho*et al.*, 2010).Stoner is considered the father of commercial aeroponics. Stoner's aeroponic systems are found in several of the world's most industrialized countries.

His aeroponic ideas, techniques, and equipment are extensively employed by top agricultural colleges across the world, as well as commercial farmers.

What is Aeroponics System?

Aeroponics, a technique derived from the 'Latin' words 'aero' meaning air and 'ponic' referring to labour or work, entails the cultivation of plants in an environment devoid of soil or aggregate media, utilizing air or mist instead. Unlike conventional methods like hydroponics, aquaponics and in-vitro growing, aeroponics represents an innovative approach to soil-less cultivation in controlled growth settings. In this method, plant roots are enclosed within a dark chamber and nourished with a misted nutrient solution. Widely adopted in horticulture, especially for crops like tomatoes, lettuce and cucumbers, aeroponics has also proven effective for seed production, meeting the demand for efficient and high-quality seed cultivation methods. Notably, aeroponic systems have found success in Korea for potato seed tuber production, outpacing traditional hydroponic systems in mini tuber production efficiency.

Aeroponics vs Hydroponics

Hydroponics is a method of growing plants in a nutrient-rich water solution without the use of soil. In hydroponic systems, plant roots are submerged or continuously exposed to the nutrient solution, which is circulated or aerated to ensure proper oxygenation. The roots absorb nutrients directly from the solution, allowing for faster growth rates and higher yields compared to soil-based cultivation. Hydroponic systems can be classified into various types, including deep water culture (DWC), nutrient film technique (NFT), drip irrigation and ebb and flow systems, each with its unique advantages and limitations. Hydroponics is well-suited for a wide range of crops and is particularly popular in commercial greenhouse operations, urban farming and home gardening (Heidi *et al.*, 2006; Kim *et al.*, 1999 and Ritter *et al.*, 2001).

Aeroponics is a more advanced form of hydroponics that involves suspending plant roots in a nutrient mist or fog rather than submerging them in a liquid solution. Plants are typically grown in vertical towers or enclosed chambers, where a nutrient solution is sprayed onto the roots at regular intervals using misting nozzles or ultrasonic devices in aeroponic systems. This method allows for maximum exposure of the roots to oxygen and nutrients, promoting rapid growth and efficient nutrient uptake. Aeroponics offers several advantages over traditional hydroponics, including faster growth rates, higher yields, and reduced water and nutrient consumption. It also eliminates the risk of waterlogging and root diseases commonly associated with submerged root systems. Aeroponics is well-suited for growing a wide range of crops, including leafy greens, herbs, strawberries, and even certain fruiting plants like tomatoes and peppers. It is particularly popular in vertical farming systems and space-limited environments, where maximizing production efficiency and space utilization are paramount.

How to better aeroponics cultivation as compared conventional agriculture?

Aeroponics stands as a superior alternative to soil-based cultivation in several key aspects. In aeroponics system, its streamlined setup process reduces logistical complexities, through offering a one-time installation requirement compared to the repetitive setup needed for soil-based systems. Moreover, aeroponics showcases exceptional reduced 96% of the water typically consumption as compared soil-based farming that addressing concerns of water scarcity and conservation. The ability to harvest monthly ensures a consistent and reliable yield throughout the year in aeroponics system. Additionally, aeroponics eliminates the necessity for insecticides, promoting environmentally friendly farming practices and ensuring the production of pesticide-free crops. Furthermore, by minimizing fertilizer usage, aeroponics reduces chemical inputs and their associated environmental impacts. Its independence from weather and soil conditions offers unmatched flexibility and resilience, making aeroponics a highly efficient, sustainable, and innovative solution for modern agricultural needs.

Types of aeroponics system:

1. Low-pressure system: This system, known for its simplicity and cost-effectiveness, involves suspending plants above a reservoir of nutrient-rich water. A low-pressure pump is used to spray the roots of the plants with this nutrient solution. Subsequently, the excess solution drips back into the reservoir below, where it is recycled and reused. However, it's important to note that this system does not involve the removal of unwanted materials or the purification of the nutrient solution.

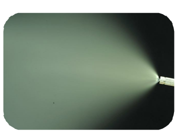
2. High-pressure system: High-pressure pumps generate mist in this system, which operates on a similar principle to low-pressure units but employs a high-pressure pump instead. Typically utilized for high-value crops, these units include a purification system unlike their low-pressure counterparts. This purification system serves for nutrient sterilization and facilitates pressurized delivery of nutrients to the plants.

3. Commercial System: This system is very much like high pressure units but has more beneficial and convenient features. Some features include: disease prevention, precision timing, temperature sensors and many more like high pressure systems, commercial systems are used for high valued crops.

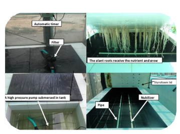
Benefits of aeroponics (Lakkireddy*et al.*, 2012)

1. **Increase Water Efficiency**: Aeroponics uses significantly less water compared to traditional soil-based agriculture because it delivers nutrients directly to the plant roots in a mist or aerosol form. This allows for precise control over water usage to minimizing waste.
2. **Increase Nutrient Efficiency**: Nutrient solutions in aeroponics systems are finely misted onto the plant roots, ensuring that the plants receive an optimal amount of nutrients. This efficient nutrient delivery system can lead to faster growth rates and higher yields compared to traditional methods.
3. **Increase Space Efficiency**: Aeroponic systems can be designed vertically, allowing for maximum space utilization. This is especially beneficial in urban environments or areas with limited space for traditional agriculture.
4. **Reduced Pest and Disease Risk**: Since aeroponic systems typically don't use soil, there is a lower risk of soil-borne pests and diseases. Additionally, the controlled environment of aeroponic systems makes it easier to monitor and manage pests and diseases, reducing the need for chemical pesticides.
5. **Faster Vegetative Growth as well as Higher Yields**: Plants grown aeroponically often exhibit faster growth rates and higher yields compared to those grown in soil. The precise control over environmental factors such as nutrient levels, pH, and temperature allows for optimal growing conditions, resulting in healthier and more productive plants.
6. **Increase quality**: In aeroponics, several studied has shown that increase flavonoids content in crops.
7. **Sustainable Farming**: Aeroponics can be a sustainable farming method, particularly when paired with renewable energy sources and efficient water management practices. It reduces the need for land and can be implemented in various locations, including urban areas and regions with poor soil quality.

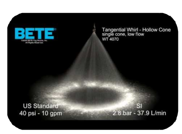
Key Component of Aeroponics system?



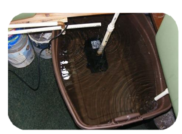
Spray misters



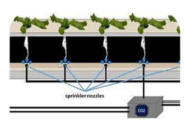
High pressure water pump



Droplet size



1.Reservoir



1.Monitering and control system

1.Growing chambers

1. **Spray misters**: Atomization is achieved by pumping water through nozzles at high pressure, which come in various spray patterns and orifice sizes. Larger nozzles and orifices decrease

the likelihood of clogging but require higher pressure to operate and have greater flow rates. It's important to select nozzles that produce the desired droplet size to ensure adequate coverage at the intended rate and pressure. For High-Pressure Aeroponics (HPA), the classification is fine atomization, producing a mist of 10 to 100 microns. Hydro atomization results in water and nutrient solution droplets ranging from 5 to 50 microns in diameter. Jet nozzles with a 0.025-inch orifice, operating at 80 to 100 psi, deliver droplets ranging from 5 to 50 microns per second, while spray jets with a 0.016-inch orifice, at the same pressure, produce droplets ranging from 5 to 25 microns per second.

2. **High pressure water pump**: High-pressure aeroponics necessitates a pump capable of generating sufficient pressure to atomize water into droplets of the optimal size from 20 to 50 microns. It is essential for the pump to consistently maintain a pressure of 80 Psi while ensuring the necessary flow of nutrients.
3. **Droplet size**: For most plant species, the optimal droplet size falls within the range of 20 to 100 microns. Smaller droplets within this range contribute to air saturation which is helping to maintain humidity levels within the growth chamber. On the other hand, larger droplets ranging from 30 to 100 microns come into more direct contact with the roots. Droplets smaller than 30 microns tend to linger in the air like a fog, while those exceeding 100 microns are prone to falling out of the air before reaching the roots. Excessively large water droplets can lead to reduced oxygen availability for the root system.
4. **Reservoir**: In an aeroponics system, the nutrient reservoir serves as a vital component, providing essential elements for plant growth. This reservoir acts as a holding tank for a nutrient-rich solution, which is then delivered to the plant roots in the form of a fine mist or spray. Furthermore, the nutrient reservoir helps to minimize wastage of nutrients.
5. **Monitoring and control system**:

   pH and EC: The pH and EC levels of the nutrient solution are crucial for ensuring successful plant growth. The ideal pH and EC range for each plant species vary depending on prevailing environmental conditions (Sonneveld and Voogt, 2009). It's important to note that the pH and EC values of the prepared nutrient solution should not exceed 7 and 2.5 ds m^{-1}, respectively. In aeroponic systems, the optimal EC range for the nutrient solution is typically between 1.5 to 2.5 ds m^{-1}, with pH levels ideally falling between 5.5 to 6.5 (Resh, 2004; Chadirin*et al.*, 2007). These specific pH and EC parameters play a significant role in ensuring the health and vigor of plants grown in aeroponic setups, contributing to their overall growth and productivity.

Table 1: Optimum pH and EC for different vegetable crops in aeroponics system

Plants	pH	EC (ds/m)
Cucumber	5.8-6.0	1.7-2.2
Carrot	5.8-6.4	1.6-2.0
Lettuce	5.5-6.5	0.8-1.2
Tomato	5.5-6.5	2.0-5.0
Potato	5.0-6.0	2.0-2.5
Onions	6.0–7.0	1.4–1.8
Spinach	5.5–6.6	1.8–2.3

Temperature: For rapid plant maturation in aeroponic systems, it's essential to regulate both the air and nutrient solution temperatures. Elevated temperatures accelerate chemical processes but can also impair enzyme activities. The ideal temperature range for all plants typically falls between 15-25 °C. It's crucial to ensure that the temperature within the growth chamber remains below 30 °C and above 4 °C (Otazu*et al.*, 2014). This balance can be upheld through the use of air conditioning, exhaust fans, and proper ventilation strategies. Controlling temperature within these specified limits is pivotal for optimizing plant growth and ensuring the overall success of aeroponic cultivation.

Light: A crucial aspect of aeroponic systems is providing adequate light in place of sunlight. This can be achieved by using fluorescent tubes with the necessary intensity. Recently, Light Emitting Diodes (LEDs) have gained popularity as a new light source in aeroponic setups, offering flexibility in adjusting various light environments to meet the specific needs of plants.

Misting frequency: In aeroponic systems, the timing of atomization spray and intervals between sprays are critical factors for ensuring successful plant cultivation. These timings are determined based on the specific needs of the plants being grown. Deviating from the appropriate schedule could result in significant challenges for plant growth, as there is no physical medium to support the plants within the system. Hence, precise control over spray timing and intervals is crucial to provide optimal conditions for plant development and avoid potential setbacks.

Table 2: Essential mineral elements concentration used in aeroponics system

	Steiner (1984)	Cooper (1988)	Hewitt (1966)	Hoagland and Arnon (1938)
Nutrient	mg L^{-1}			
N	168	200-236	168	210
P	31	60	41	31
K	273	300	156	234
Ca	180	170-185	160	160
Mg	48	50	36	34
S	336	68	48	64
Fe	2-4	12	2.8	2.5

Cu	0.02	0.1	0.064	0.02
Zn	0.11	0.1	0.065	0.05
Mn	0.62	2.0	0.54	0.5
B	0.44	0.3	0.54	0.5
Mo	Not considered	0.2	0.04	0.01

Humidity and dissolved oxygen concentration: Humidity in the growth chamber refers to the quantity of water present as water vapor, a crucial factor for supporting plant growth and development. The level of humidity is greatly influenced by fluctuations in relative humidity. Maintaining and controlling the humidity within the growth chamber according to the specific needs of the plants is essential. In aeroponic systems, an optimal oxygenation environment is provided for plant growth, enabling roots to thrive in the air with ample oxygen supply. This setup ensures favorable conditions for healthy plant development.

6. **Growing chambers**: In aeroponics systems, the nutrient growing chamber is a central component where plant roots are suspended and exposed to a nutrient-rich mist or spray. This chamber provides an ideal environment for root growth and nutrient absorption, promoting healthy plant development. The design of the nutrient growing chamber varies depending on the specific aeroponic system, but it typically consists of a container or chamber where plants are held in place, allowing their roots to hang freely. The chamber may be constructed from various materials such as plastic, PVC, or even specialized aeroponic growing towers designed to maximize space efficiency. The primary function of the nutrient growing chamber is to support the roots and facilitate nutrient uptake. One of the key advantages of the nutrient growing chamber in aeroponics is its ability to provide a highly oxygenated environment for the roots.

How to Work aeroponics system?

The aeroponic system offers a continuous cultivation process within a limited space, reducing the need for agricultural labour. Aeroponics involves cultivating vegetables whether, suspending plants in a closed or semi-closed environment and spraying their dangling roots and lower stems with a nutrient-rich water solution in an atomized or sprayed form.

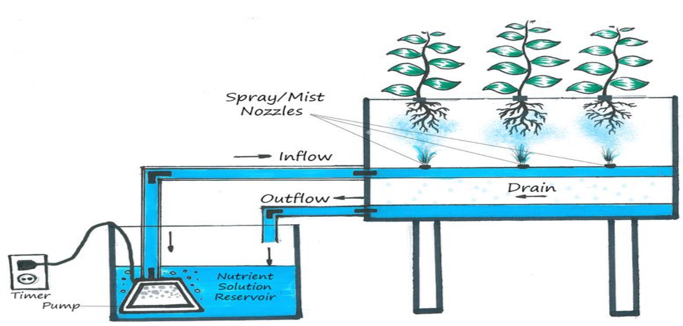


Fig. 1: Working of aeroponics system

A well-designed aeroponic setup includes an effective monitoring and control system to ensure optimal distribution of water and nutrients. This setup typically consists of a network of pipes, spray nozzles, a pump and a timer for distributing the nutrient solution stored in a tank. Utilizing small internal micro jet sprays, the system delivers a fine, high-pressure mist containing nutrient-rich solutions to the roots within the rooting chamber. A programmable cyclic timer is employed to activate the high-pressure aeroponic pump at scheduled intervals. Nutrients are blended with water in a reservoir basin, filtered, and then pumped into a pressurized holding tank, where they are intermittently misted onto the root system.

Mature root hairs play a crucial role in efficiently absorbing nutrients from moisture, facilitating the administration of various nutrients to the plant through the root system. The small size of the spray particles minimizes wastage of the nutrient solution. Additionally, adequate oxygen supply prevents root rot entirely.

Aeroponics in vegetable crops: Different vegetable crops (such as, tomato, bell pepper, potato, lettuce, yam, carrot, watermelon, kale, leafy vegetables, etc.) can be grown in aeroponics cultivation.

Table 3: Effect of aeroponics system on vegetable crops

Crop	Result	References
Potato	highest average number of tubers and yield per plant	Ritter *et al.* (2001)
	quality seed potatoes	Christie and Nichols (2004)
	Highest potatoes seed tubers in soil-less system	Irman *et al.* (2012)
	limits stolon growth and triggers tuber initiation	Chang *et al.* (2012)
	highest yield/plant	Farran and Mingo (2006); Tierno *et al.* (2013); Bag *et al.*(2015); Brocic*et al.*(2018);
	maximum number of buds	Budiasih*et al.*(2020)
Tomato	maximum average yield per plant	Osvald *et al.* (2001); Chandra *et al.*(2014)
Yams	maximizing yields	Darko *et al.* (2017)
Lettuce	growth and yield of lettuce	Demsar*et al.* (2004)

	growth of shoot and root	He and Lee (1998)
	producing hearted	Luo *et al.* (2009)
	highest fresh mass (290.84 g/plant) and dry mass (39.41 g/plant) of shoot	Ali *et al.* (2015)
	maximum leaf area, stem diameter, number of leaves per plant, shoot length, root length, shoot wet weight, root wet weight, shoot dry weight, and root dry weight	Lakhiar*et al.* (2019)

1. **Potato:** Ritter *et al.* (2001) reported that the aeroponics system achieved the highest average number of tubers and yield per plant. This finding underscores the effectiveness of aeroponics in optimizing tuber production and overall plant yield. Christie and Nichols (2004) utilized aeroponics for the large-scale cultivation of premium quality seed potatoes and the cultivation of gourmet early (new) potatoes. Upon investigating the initial growth stages of potatoes in hydroponic systems, it becomes evident that the root system develops significantly earlier than the stolons responsible for tuber formation. An advantage of this system is its ability to synchronize tuber production, enabling the simultaneous cultivation of a substantial quantity of uniformly sized tubers.Farran and Mingo (2006) observed that a lower planting density combined with a weekly harvesting interval resulted in increased yields of seed potato tubers. Reducing planting density might allow each plant to have better access to resources such as water, nutrients, and sunlight, thereby promoting more vigorous growth and higher tuber production per plant. The weekly harvesting interval may have facilitated better resource allocation within the plants. By harvesting the tubers more frequently, the plants may have been prompted to allocate more energy towards tuber production as they continuously respond to the removal of tubers, thus resulting in higher yields.Irman *et al.* (2012), explored strategies for rapidly multiplying seed tubers, including the combination of tissue culture with hydroponic and aeroponic systems to address the challenge of inadequate supply of high-quality seeds. Chang *et al.* (2012) observed that interrupting nutrient supply during the stolon growth stage significantly enhances root activity, limits stolon growth and triggers tuber initiation. Consequently, conditions unfavourable for tuberization. Although, High temperatures and late-season cultivars are conducive to employing this nutrient interruption method, particularly in hydroponic seed potato production. Tierno *et al.* (2013) compared production of three potato cultivars under

aeroponics and greenhouse beds and they noticed highest yield/plant (88.6 g/plant) from cv. Monalisa.Bag *et al.*(2015) compared yield performance of potato mini-tubers of three varieties under aeroponics system for two years (2013 and 2014). They found that Kufri Megha showed better performance with respect to days to tuberization (32.67 and 30.00), number of mini-tubers/plant (42.68 and 38.11), yield of mini-tubers/plant (118.54 g and 108.94 g) and average mini-tuber weight (2.91 g and 2.96 g), while Kufri Himalini found better in day to senescence (127.00) in 2013 and yield of mini tuber/ plant (161.80) in 2014. Tessema *et al.*(2017) found that application of 59 g $CaNO_3$, 126 g KNO_3, 68 g KH_2PO_4 and 100 g $MgSO_4$ nutrient solution produce maximum number of tuber/plants with potato cv. Belete. Brocic*et al.*(2018) studied the influence of the potato cultivar on the number and mass of potato mini-tuber in the aeroponics system and it was evident that the highest number of mini-tubers/m^2 (373.26) and average number of mini-tubers/plant (15.55) were recorded from the cv. Desiree, while maximum yield of mini-tuber/m2 (2304 g/m^2) and average mass of a mini-tuber (8.97 g) were obtained from cv. Agria. Budiasih*et al.*(2020) found the maximum number of buds in the 20 × 25 cm spacing with room temperature (control) treatment and number of tuber formed in 20 × 25 cm spacing with 15°C temperature treatment.Recently, the International Potato Center (CIP) introduced a novel aeroponics system for mini-tuber production, highlighting its effectiveness. Research outcomes indicate that aeroponics can yield a greater quantity of tubers with increased weight. Plants sanitized through meristem culture and induced to tuberize under the aeroponic system rapidly produce high-quality potato seed tubers, free from pathogen contamination. This streamlined process allows for direct transplantation into the main field, simplifying tuber multiplication. As a result, aeroponics shows promise for boosting income and reducing production costs associated with quality seed, thereby improving accessibility for growers in developing countries where potato production is hampered by the use of subpar seed tubers.

2. **Tomato:** Osvald *et al.* (2001) conducted a study on the yield of tomato cv. 'Arletta' cultivated in aeroponics with varying plant densities, specifically 24, 32, 40, and 48 plants per square meter. They observed that the maximum average yield per plant (526 g) was achieved with a lower plant density of 24 plants per square meter, whereas the maximum average yield per square meter (21.2 kg) was recorded with a higher plant density of 48 plants per square meter. Chandra *et al.* (2014) undertook a comparative analysis of the average yield of various vegetables cultivated in both field and

aeroponics systems. Their findings revealed that the aeroponics system consistently yielded the highest average yield per plant and the highest average number of fruits per plant. These studies underscore the influence of plant density and cultivation method on crop yield.

3. **Yams:** Aeroponics technology emerges as a promising method for yam propagation, accommodating genotypes of both D. rotundata and D. alata through the use of pre-rooted and fresh vine cuttings. Studies have shown successful root formation of vine cuttings from five-month-old plants, with an impressive 95% rooting rate achieved within a span of 14 days in aeroponics. Across five different genotypes, an average rooting rate of 83% was recorded, with individual rates ranging from 68% to 98%. However, the performance of genotypes varied when it came to mini-tuber production in aeroponics. Yam mini-tubers harvested from aeroponics exhibited diverse weights ranging from 0.2g to 110g, influenced by factors such as genotype, harvest age, and nutrient solution composition. It's worth noting that the sensitivity of this system to excessive heat necessitates careful temperature regulation to ensure optimal performance.Darko *et al.* (2017) further demonstrated the potential of aeroponics technology, particularly in power-dependent units, for maximizing yields in yam propagation. Specifically, their findings highlighted that the cultivar Mankrong Pona of white yam achieved maximum mean yield per cutting (3.67 g), multiplication ratio per explant (477.10), and number of seed yam per explant (1393) in the aeroponics setup. Overall, these studies underscore the efficacy of aeroponics technology in yam propagation, offering opportunities for enhanced productivity and efficiency. However, attention to factors such as genotype selection, nutrient management, and temperature control is crucial to optimize outcomes in aeroponic systems for yam cultivation.

4. **Lettuce:** Demsar*et al.* (2004) investigated the impact of light-dependent nitrate application on the growth and yield of lettuce cultivated aeroponically. Meanwhile, He and Lee (1998) observed that the growth of shoot and root, as well as the photosynthetic responses of three lettuce cultivars under varying root zone temperatures and growth irradiances in tropical aerial conditions, were superior in aeroponically grown crops compared to the control. Luo *et al.* (2009) devised a highly effective method for producing hearted lettuce in tropical regions using aeroponics coupled with root cooling. Furthermore, He *et al.* (2010) explored the effects of elevated root zone CO_2 and air temperature on photosynthetic gas exchange, nitrate uptake, and total reduced nitrogen

content in aeroponically grown lettuce plants.In a comparative study by Ali *et al.* (2015) between aeroponics and hydroponics systems, the aeroponics system, particularly at a flow rate of 0.5 L/h, exhibited the highest fresh mass (290.84 g/plant) and dry mass (39.41 g/plant) of shoot. Lakhiar*et al.* (2019) investigated the influence of different aeroponic atomizers (A_1= air-based, A_2= airless atomizer, and A_3 = ultrasonic fogger) on various growth parameters of lettuce. They reported that A_2 resulted in maximum leaf area, stem diameter, number of leaves per plant, shoot length, root length, shoot wet weight, root wet weight, shoot dry weight, and root dry weight.

5. **Leafy vegetable:**

A study comparing product yield, total phenolics, total flavonoids, and antioxidant properties across various leafy vegetables/herbs (basil, chard, parsley, and red kale) and fruit crops (bell pepper, cherry tomatoes, cucumber, and squash) grown in both aeroponic systems and traditional field settings was conducted. Results indicated an average increase of approximately 19%, 8%, 65%, 21%, 53%, 35%, 7%, and 50% in yield for basil, chard, red kale, parsley, bell pepper, cherry tomatoes, cucumber, and squash, respectively, when cultivated in aeroponic systems compared to soil-based cultivation. Overall, plants grown aeroponically exhibited higher yields and comparable levels of phenolics, flavonoids, and antioxidant properties to those grown in soil.

Constrain of aeroponics (Waiba*et al.*, 2020)

1. **High Initial Cost**: Setting up an aeroponic system can be expensive due to the need for specialized equipment such as misters, pumps, and timers. The initial investment in infrastructure and technology can be a barrier for some growers, especially small-scale or hobbyist farmers.
2. **Technical Complexity**: Aeroponic systems require precise control of environmental factors such as nutrient concentrations, pH levels, humidity, and temperature. Managing these variables effectively requires technical expertise and monitoring equipment, which may pose challenges for inexperienced growers.
3. **Risk of System Failures**: Aeroponic systems rely on pumps, misters, and other mechanical components to deliver nutrients and water to the plants. If any of these components malfunction or fail, it can disrupt nutrient delivery and potentially harm plant growth. Regular maintenance and monitoring are essential to prevent system failures.

4. **Root Drying**: If the misting intervals are not properly calibrated or if there are disruptions in misting, the plant roots in aeroponic systems may dry out quickly. This can lead to stunted growth or plant wilting, particularly in sensitive plant species. Adequate monitoring and adjustment of misting schedules are necessary to prevent root drying.
5. **Susceptibility to Pathogen Spread**: While aeroponic systems reduce the risk of soil-borne diseases, they may still be susceptible to airborne pathogens or waterborne diseases. Contaminated water sources or improper sanitation practices can lead to the spread of diseases among plants in aeroponic systems. Implementing strict hygiene protocols and using sterilized water can help mitigate this risk.

❖ **Aeroponics farming in India**

- Aeroponics farm at Palladam, Tamil Nadu
- Sure Grow, Tamil Nadu
- Aeroponics Cultivation Consultancy, New Delhi
- CPRI, Shimla (aeroponics system for potato mini tubers production)

❖ **Aeroponics farming in world**

- Aeroponics at NASA,US
- Scissortail Farms in Tulsa, Oklahoma (United States)
- Aero-Philadelphia, Pennsylvania
- Agricool, aeroponics vertical farms, France
- Tower farms (aeroponics), ALTIUS, Colorado, US

Conclusion

In conclusion, the global population rise and diminishing arable land necessitate innovative agricultural solutions. Aeroponics emerges as a promising method, offering water and nutrient efficiency, space optimization, and reduced pest risks. Despite initial costs and technical complexities, its benefits in yield, quality, and sustainability position aeroponics as a key player in future agriculture.

References

1. Anonymous (2017). Department of Economic and Social Affairs, United Nations. https://www.un.org.
2. Anonymous (2017). ICAR-National Institute of Abiotic Stress Management, Malegaon (Kh), Baramati, MH. https://niasm.icar.gov.in.
3. OERKE, E.C., DEHNE, H.-W., SCHO¨NBECK, F. & WEBER, A. (1994). Crop Production and Crop Protection – Estimated Losses in Major Food and Cash Crops. Amsterdam: Elsevier Science.

4. Barak, P., Smith, J.D., Krueger, A.R., Peterson, L.A., 1996. Measurement ofshort-term nutrient uptake rates in cranberry by aeroponics. *J. Plant. Cell Environ*. 19, 237–242.
5. Kim, H.S., Lee, E.M., Lee, M.A., Woo, I.S., Moon, C.S., Lee, Y.B., Kim, S.Y., 1999.Production of high quality potato plantlets by autotrophic culture for aeroponic systems. *J. Korean Soc. Hortic. Sci*. 123, 330–333.
6. Ritter, E., Angulo, B., Riga, P., Herrán, C., Relloso, J., 2001. Comparison of hydroponic and aeroponics cultivation systems for the production of potato minituber. Netherlands. *Am. J. Potato Res*. 44 (2), 127–135.
7. Farran I, Mingo-castel AM. 2006. Potato minituber production using aeroponics: Effects of density and harvest intervals. *Am. J. Potato Res*. 83(1):47-53.
8. Otazu, V., 2010. Manual on Quality Seed Potato Production Using Aeroponics. International potato Cenre (CIP), Lima, Peru, 44 p.
9. Lungaho, C., Nyongesa, M., Mbiyu, M.W., Nganga, N.M., Kipkoech, D.N., Pwaipwai,P., Karinga, J., 2010. Potato (Solanum tuberosum) Minituber Production Using Aeroponics: Another Arrow in the Quiver. Kenya Agricultural ResearchInstitute, Tigoni, pp. 168 p.
10. Heidi A. Kratsch, William R. Graves, Richard J. Gladon. Aeroponic system for control of root-zone atmosphere. Environmental and Experimental Botany. 55 (2006) 70–76.
11. Chang, D.C., Park, C.S., Kim, S.Y., Lee, Y.B., 2012. Growth and tuberization of hydroponically grown potatoes. Potato Res. 55, 69–81.
12. Christie. C.B and M.A. Nicholas. 2004. Aeroponics - A production system and research tool. Acta Hort. 648, ISHS.
13. He Jie and Lee Sing Kong. 1998. Growth and photosynthetic responses of three aeroponically grown lettuce cultivars (*Lactuca sativa* L.) to different root zone temperatures and growth irradiances under tropical aerial conditions. The Journal of Horticultural Science and Biotechnology. 73 (2): 173-180.
14. Irman, I., Muhammad and Ikhsan Sani. 2012. Monitoring and control of aeroponic growing system for potato production. IEEE Conference on Control, Systems and Industrial Informatics (ICCSII):23-26.
15. Je He., Paul T.Austin and Sing Kong Lee. 2010. Effects of elevated root zone CO_2 and air temperature on photosynthetic gas exchange, nitrate uptake, and total reduced nitrogen content in aeroponically grown lettuce plants. *Journal of Experimental Botany*.
16. Lakkireddy K. K. R., Kasturi K., Sambasiva Rao K. R. S. 2012.Role of Hydroponics and Aeroponics in Soilless Culture in Commercial Food Production. *Journal of Agricultural Science & Technology*. Vol 1, (1), 26-35.
17. Lungaho, C., Nyongesa, M., Mbiyu, M.W., Nganga, N.M., Kipkoech, D.N., Pwaipwai,P., Karinga, J., 2010. Potato (Solanum tuberosum) Minituber Production Using Aeroponics: Another Arrow in the Quiver. Kenya Agricultural ResearchInstitute, Tigoni, pp. 168 p.
18. Luo, H.Y., S.K. Lee and J. He. 2009. Integrated effects of root-zone temperatures and phosphorus levels on aeroponically-grown lettuce (*Lactuca sativa* L.) in the tropics. *The Open Horticulture Journal*, 6-12.
19. Thielert, W. (2006). A unique product: the story of the imidacloprid stress shield. *Proceedings of the Science Forum*, 59 (1), 73-86.
20. Kratsch, H. A., Graves, W. R., &Gladon, R. J. (2006). Aeroponic system for control of root-zone atmosphere. *Environmental and Experimental Botany*, *55*(1-2), 70-76.

21. Barker B.T.P. (1922) Studies on root development. Long Ashton Research Station Annual Report 1921, 9-57.