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Recent Advancements in Prevalent Practices for Plant Cultivation by Hydroponics

Utkarsha Srivastava and Ashwani Mathur

Department of Biotechnology, Jaypee Institute of Information Technology, A-10, Sector-62, Noida–201 309, Uttar Pradesh, India
Email: ashwani.mathur@mail.jiit.ac.in

ABSTRACT

Many plant-derived products are well known to possess therapeutic properties along with minimum side effects and relatively competitive efficacies as compared to other chemical counterparts/analogs. Herbal drugs are therefore now widely accepted owing to their long-lasting impact. However, the role of cultivation conditions and associated biotic and abiotic parameters are paramount in affecting the yield of phytocompounds among cultivated plants. Moreover, with the increasing burden on cultivable land available for the production of cash crops, medicinal plants require alternative techniques of propagation for meeting commercial demands without adversely affecting their yield of phytocompounds and their therapeutic potential. Regulating the biotic and abiotic parameters using several methods of propagation (viz. vegetative and plant tissue culture) is instrumental in attaining the desired yield in the harvest. The major drawbacks of these techniques are lack of skilled labour and high monetary expense. Alternative techniques, such as hydroponics and aeroponics are pivotal to overcoming these disadvantages. The 'Hydroponics' technique involves plant cultivation in a soil-less nutrient medium. This method offers major advantages over the conventional techniques being more economical and independent of seasonal variations besides eliminating the influence of soil-microbe interactions on the development of plants. This technique is under continuous investigation and improvement with recent advances being made in the inter-disciplinary approaches for improving the technique by the addition of IoT and cloud computing along with other conventional techniques such as vertical farming for hydroponic systems and the development of hybrid models.

Keywords: Plant cultivation; Hydroponics; Tissue culture; Computational techniques

1. INTRODUCTION

The agriculture sector holds a major share economically as reported by the World Bank. Positive pressure is increasingly being created on natural resources including cultivable land to meet the demands of food for the rising population which has raised the need to identify sustainable alternatives for cultivation. Different approaches have been identified for the incubation of alternative techniques which may include modification of growth medium, development of better yielding varieties of crops via cross-breeding, plant tissue culture, and co-cultivation. Soil-less technique as a modification of growth medium is now being considered a realistic alternative for decreasing the demand and burden on cultivable land for crop production. These methods include hydroponics, aeroponics, and aquaponics[1].

Hydroponics is the technique of growing plants in a liquid medium without soil support. An advancement of hydroponics is aeroponics- the system of cultivation in which the plants are suspended freely in air while the nutrient mist is sprayed on them. Aquaponics is an advancement of aquaculture in which fishes are cultured and their waste produced serves as a nutrient source for the plants cultivated hydroponically simultaneously. Among these, hydroponics is the most explored and evaluated system of cultivation due to the disciplined management of resources and efficient food production. This is because hydroponics offers major advantages over aeroponics and aquaponics which include the requirement for lower financial input for hydroponics, suitable for cultivation of a larger variety of plants as compared to aeroponics, more sustainable since it offers water recycling and is also an easier medium to establish a plant from the soil in a soil-less system. Hydroponics is currently employed to develop a vast range of regional crops with economic profit such as tomatoes, peppers, green leafy vegetables, strawberries, and cucumbers. Vegetables such as spinach and lettuce grow abundantly in aquaculture and hydroponics[2].

Hydroponics is the technique of growing plants in a soil-less medium by immersing the roots in a nutrient solution. The term "hydroponics" is derived from two Greek words, "hydro" meaning "water" and "ponics" meaning "to work". This is an effective approach to address both the decreasing availability of cultivable land and the difficulties in plant growth due to climatic variations as reported by Jensen and Malter (1995)[3]. This system is also efficient in reducing malnutrition and

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utilizing natural resources. A major hindrance in this technique will be the continuous requirement of clean contamination free and chemical-free water[4]. This system will boost the output by reducing dependency on pesticides and fertilizers and water consumption. Hydroponics can overcome the hurdles of conventional farming by allowing cultivation even in unconventional regions such as desert areas that have an arid climate. Conversely, it will also permit cultivation in densely populated areas which lack cultivable land[5]. It is under extensive evaluation and development for further improvements.

2. CURRENT METHODS OF PLANT PROPAGATION

Plant propagation under controlled culture conditions is a means of reproduction and regeneration of plant species while incorporating certain traits in them or to obtain true to type germplasm for establishing a pure variety. Several modes of propagation can be considered which includes vegetative means which use vegetative parts of a plant for propagation, plant tissue culture techniques for plant propagation under sterile in-vitro conditions, and certain alternative strategies. Table 1 gives an overview of these techniques.

The in-vitro tissue culture technique involves certain disadvantages. The plant tissue culture technique, although, helps to develop disease-free plants besides protecting and storing the germplasm, requires continuous scrutiny and is labour-intensive and costly. It requires extremely sterile conditions free from contamination. Culturing of plants by this technique affects the molecular pathways and thereby the production of secondary metabolites. Such in-vitro-grown plants require a moisture-rich environment due to the high sensitivity of plants but also favour microbial growth and contamination of the culture. Acclimatization of tissue culture plants is a very crucial step. Unacclimatized plants experience water loss due to a lack of stomatal closures causing the death of the plant[8].

Apart from the aforementioned drawbacks, other loopholes of plant tissue culture majorly involve high costs for both tissue culture medium and electricity. It also requires skilled labour. Certain studies have attempted to overcome this problem by utilizing alternative sources of sucrose as household sugars and other sources of carbon as various starches besides studying the effect of different gelling agents as plum gums as an alternative to agar. Another problem of the tissue culture technique is the genetic instability of the plants developed via this method. Different studies have reported that in-vitro-generated plants are not necessarily clonal copies

Table 1. Broad overview of the different techniques for plant propagation

Method	Technique	Description	Advantages	Disadvantages
Vegetative propagation[6]	Cutting	Rooting a piece of the parent plant	Cost-effective and produces uniformly large quantities of plant	Difficult rooting and growth. Recalcitrant to PGRs
	Layering	Stem roots while still attached to the mother plant. It is removed and planted in soil for further development	Mother plant supplies nutrients and resources for the development of the new plant	It is a slow process and is limited to a few species only
	Grafting	Shoots of two plants (rootstock and scion) grafted together to grow as one	Compatible shoots grow well together.	The compatibility of the two stocks to be used needs to be determined
	Budding	Axillary bud is attached to the scion	Overcomes the limitations of grafting when limited plant material is available	Influenced by environmental conditions
Plant tissue culture [7]	Suspension culture	Single cells or small aggregates of cells are suspended in a liquid medium and allowed to multiply.	High productivity	High risk of contamination
	Protoplast culture	The technique of somatic hybridization which involves the isolation of and fusion of protoplasts and the development of hybrid cells	High transformation frequency	Requires careful handling of protoplast and the hybrid cells. Yield is small
	Callus culture	Growth of undifferentiated mass of cells (callus) under nutrient-rich aseptic conditions	Helps in obtaining secondary plant products	Requires controlled conditions and is labor-intensive and costly
	Apical meristem culture	Growth or regeneration of plant from the apical meristem of shoots	Development of virus-free plants	Low survival rate
	Microspores and anther culture	Uses reproductive parts as pollen and pollen tubes for the development of new plant	Simple responsive and less time consuming	Economically not viable for haploid production and is labor intensive

of the parent plant. Growth regulators used in in-vitro conditions act as stress factors that activate the stress response in the plant inducing alterations in their genome which further generates instability in cultured cells which is commonly known as somaclonal variation[9-12]. These genetic alterations may include polyploidy, alternative methylation of DNA, activation of transposable elements, amplification, change in chromosome number, and change in DNA sequence.

According to a report by Pierik in 1988 major limitations of in-vitro techniques include frequent mutations, difficulty in the propagation of woody species, contamination of plant material and infection, lack of knowledge on the basic technique, vitrification, negligence on the role of physical factors as light, humidity and air, exudation of toxic chemicals due to activation of stress response factors and prominent changes in levels of different gases as ethylene and carbon dioxide[13].These limitations raise the requirement for an alternative strategy to stably propagate plants for both in-vitro conditions and at an industrial scale.

3. ALTERNATIVE TECHNIQUES FOR PLANT PROPAGATION: HYDROPONICS

Hydroponics is a method of cultivating plants in nutrient rich solution without necessarily utilizing a physical support like gravel, vermiculite, rock wool, peat moss, sawdust, coir dust, fibres of coconut, etc. Professor William Gericke was the first to introduce the term "hydroponics" in the early years of 1930s to refer to a different approach of gro wing plants, wherein the plant with its roots were suspended in water containing mineral rich nutrient solution. Altering the growth medium is a viable solution for sustainable production and for conserving rapidly diminishing land and water resources. In the current situation, soilless farming could be successfully undertaken and regarded as an alternate option for growing wholesome food plants, crops, or vegetables[14]. Figure 1 shows a simple system of hydroponics. Hydroponics systems are customized and modified according to the recycling and reuse of nutrient solutions and supporting media.

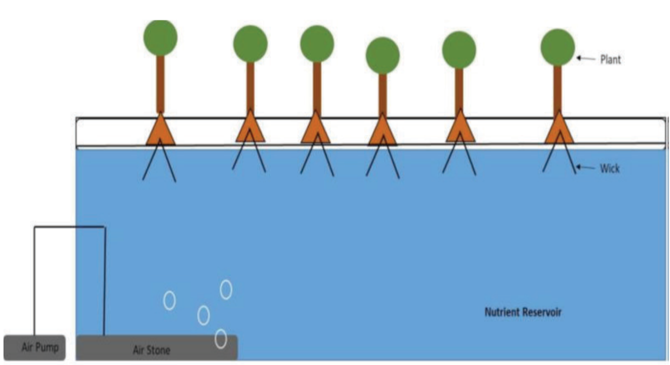

Figure 1. Hydroponics system for plant growth. The roots are shown dipped in a nutrient solution while an air pump is used to regulate air in the nutrient solution for proper aeration of the roots. (based on information by Gonzalez, *et al* (2022)[15]).

The success of the hydroponics technique lies in the ability of the system to circulate the nutrient-rich solution throughout the extensive network in which the plants are grown. This technique can, therefore, be classified based on various methods that have been employed for maintaining this circulation. Commonly used techniques are wicking, drip, ebb-flow, deep water culture, and nutrient film technique (NFT) which are described in Table 2.

Table 2. Overview of different hydroponics systems

S. No.	Hydroponic system	Description	Reference
1.	Wick system	The simplest system of hydroponic cultivation Pump, aerators, and electricity are not required A nylon wick runs through the roots into a reservoir of nutrient solution where the plants are placed in an absorbent medium. Nutrient solution provided via capillary action. Efficient for small plants, spices, and herbs.	[16]
2.	Ebb and Flow system	Works on the principle of flood and drain. A water pump is used to flood the growth bed with nutrient solution and water until a requisite level is reached which is then left to stay for a while	[17]
3.	Drip system	Individual plant roots are supplied with nutrient and water solution in required proportions with the help of a pump Conserves water Offers systematic growth	[18]
4.	The deep water culture system	Air stone is used to provide air directly to the roots that are suspended in the nutrient solution. This system is efficient for the cultivation of larger plants such as cucumbers and tomatoes.	[19]
5.	Nutrient film technique (NFT) system	Water and nutrient solution is circulated throughout the system which enters the growth tray via a water pump without any time regulation. Leafy green vegetables can be easily grown in this system. Commercially accepted for the production of lettuce.	[2]

The hydroponics systems can further be classified based on the support medium used and the techniques of nutrient circulation (Figure 2)[20].

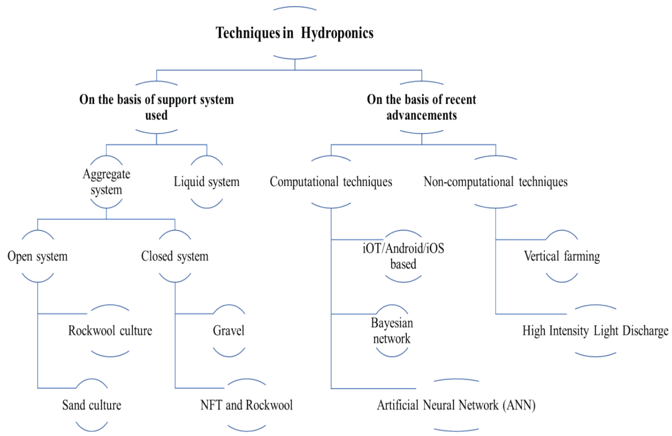

Figure 2. Classification of the different techniques used in hydroponics[20-22].

Aggregate and Liquid System of Hydroponics-

The plant material is surrounded by solid inert material for support and oxygen penetration to the roots while retaining a thin layer of nutrients and water around the roots. The materials most commonly used as aggregates include rock wool, gravels, clay pebbles, vermiculite, and sand. The Ebb and flow system of nutrient circulation is most commonly used in this technique followed by the trickle feed method[21]. This technique can further be categorized into open and closed systems (Table 3).

Table 3. Different types of aggregate hydroponics systems[22].

Type of system	Sub-category	Feature
Open system	Rockwool culture	• Rockwool- grounded basalt rock heated to make threads which are then spun into wool • Lightweight • Good water and air retention capacity
	Sand culture	• No requirement for water-tight buds • Does not require very strict maintenance • Has some major drawbacks including the coarseness and nature of sand
Closed system	Gravel	• Small size gravels used for plant support • The nutrient solution passed through to the roots of the plants by the drip system
	NFT and Rockwool	• NFT system of irrigation used • Rockwool slabs are placed in the NFT system to establish plants

The liquid system of hydroponics does not require a solid support system, unlike the aggregate system. This system is more widely accepted for growing plants since it offers better control over the system and the availability of nutrients and oxygen. Another advantage of this system is that it restricts microbial contamination by limiting the requirement for a solid support system[23]. This technique is currently being explored extensively with an interdisciplinary approach which has led to some major advancements in hydroponics.

4. RECENT ADVANCEMENTS IN HYDROPONICS

The technique of hydroponics has undergone advancements since its development and commercial application. These advancements have found the input of both computational and non-computational techniques to monitor the growth of plants and regulate the influence of abiotic factors.

4.1 Computational Techniques Hydroponics

4.1.1 IoT and Android/iOS-based hydroponics

IoT is an emerging technique studied for its usability in developing advanced hydroponics systems. IoT has allowed farmers to automate this system. It helps in monitoring and regulating the intensity of light, level of water, temperature and other associated factors. For instance, water temperature sensors have been used to detect the changes in the temperature of water in hydroponics. This helps in regulating the water temperature in different climatic conditions as low temperature conditions and cold climates when water tends to freeze. A similar pH sensor is also deployed to detect changes in the pH of the hydroponics medium which would update timely inputs of minerals into the system as per the requirement. An assortment of sensors and controllers like ESP-8266, Arduino and Raspberry Pi, etc. can be used to develop and automate a hydroponics farm[24].

A study by Ludwig and Fernandes (2013) reported the use of a microcontroller to display the conditions monitored which included pH, conductivity, and the light intensity of the hydroponics system. A microcontroller can also control the lighting of the complete system via a relay switch [25]. A report on the NFT approach of hydroponics utilizing IoT for monitoring cultivation in this system has supported this information.Different sensors were attached to the Arduino Microcontroller which worked using Wi-Fi to translate the data thus obtained to the web server. This information would be available to people and help in monitoring the efficiency of hydroponics systems making IoT an extremely reliable and effective method for monitoring NFT farms[20]. Similar investigations on the applicability of IoT in hydroponics have established the usefulness of this additional technique in regulating plant growth by utilizing suitable biosensors and storing this information in the cloud. IoT can, thus, be used for monitoring hydroponics under any environmental condition[26].

Another hydroponics model developed on a do-it-yourself android iOS application was implemented for automatic control[25]. This application controls sensors for different hydroponic systems which include regulating different abiotic factors. Such types of systems that help in controlling the environmental conditions also help in efficient planning, proper time management, and effective maintenance of records for crop harvesting data. Further, this information can be stored directly in the Cloud as recorded by the sensors. Machine learning has also promoted hydroponics by automating the growth of a plant.

A recent study on NFT-based hydroponics using vertical farming on lettuce has combined detection and automation techniques with LoRaWAN technology. This has enabled a much more efficient detection of changes in plant growth with the opportunity for analysing the correction and monitoring of key parameters. The automated system has equipped the transmission of data on long-range and low power over a wide area network[27].

4.1.2 IoT Spectroscopic Sensor

A research by Stevens, *et al* (2023) aimed to present a prototype of an optical nutrient monitoring system can be integrated into a home-based MISH system. The system, which is called NutriSpec, was constructed using a commonly available ware parts and IoT spectroscopic sensor. NutriSpec uses this system setup in conjunction with the architectures that are already established for micro indoor smart hydroponics (MISH) systems[28-29]. To demonstrate the system's effectiveness, a 28-day lettuce-growing experiment was conducted, and the NutriSpec system was used to monitor the nutrient solution dynamics created by the lettuce, which acted as a nutrient sink. This experiment was conducted in a real-world setting.

To assess the NutriSpec sensor's capability, a complete MISH system was built using standard, off-the-shelf hardware components.The system's layout, as depicted in Figure 3, was uncomplicated.The AS7265x sensor was connected to the Arduino Uno's inter-integrated circuit (I2C) bus and then to the Raspberry Pi 4 B (RPi 4B) via USB. The RPi 4B functioned as a gateway for the sensors and was linked to solid-state relays via general-purpose input-output (GPIO) pins to regulate the grow lights and water pump. For additional water monitoring, a DFRobot analog EC sensor DFR0300, a DFRobot pH analog sensor V2 SEN0161-V2, an analog water-level sensor, and a DS1820 digital temperature sensor were included. All of these sensors were connected to the Arduino Uno and the RPi 4B.

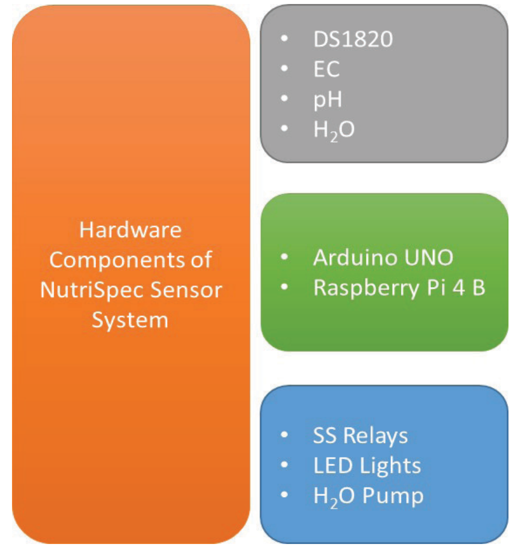

Figure 3. Hardware components of NutriSpec[30]

The objective of this research was to exhibit the practicality of utilizing an optical sensor-based inline nutrient monitoring system for precise measurements of individual nutrient changes, as opposed to traditional EC measurements. This was proof-of-concept design with the objective to establish the feasibility of using such a system to precisely assess the real-time nutrient levels. The findings indicated that the NutriSpec sensor system was capable of accurately detecting variations in nitrogen levels within a hydroponic solution in a real-world MISH system setting. The efficacy of the MLR models generated by the system was evident in indicating the superiority of spectroscopic sensors over EC measurements. These results suggest that future MISH systems can employ simple submerged optical sensors to replace traditional EC sensors[30].

4.1.3 Bayesian Network Construction

Another research by Ferentinos and Albright[31] reported the monitoring of physical events as potenz Hydrogen, water level, and electric conductivity, in hydroponics which was used for the construction of the Bayesian network. This network helped in assessing the performance of the system and further controlling it accordingly by providing GUI for sensor values displayed. BBN system was used in a hydroponics system working on a system of water reuse which is economically viable. This approach to hydroponics system allows a rough yet comprehensive overview of hydroponics.

4.1.4 Artificial Neural Network (ANN)

Artificial Neural Network (ANN) has also been reported to be useful in predicting potenz Hydrogen and electrical conductivity in hydroponics systems[32]. Input from various parameters such as light intensity, age of the plant, electrical conductivity, and other such factors was used to develop feed-forward neural networks and further provide outputs such as pH and electrical conductivity which make automation of hydroponics easier and more efficient.

Figure 4 gives an overview of different techniques incorporated into the hydroponics system to enhance the method. By leveraging the Internet of Things, hydroponic food production systems can consolidate their growth and monitoring processes into a secure cloud environment, resulting in several benefits. Firstly, IoT provides a framework for cloud-based system monitoring, which can significantly reduce maintenance costs - a major challenge in automation today. Additionally, the performance of smart hydroponic systems can be assessed through supervised machine learning algorithms for effective management. However, there is still room for improvement. This can be achieved by incorporating data analytics or machine learning to develop algorithms that can predict outcomes, installing additional sensors for more precise data, and supporting the Artificial Intelligence system in making predictions[33].

4.2 Non-computational Techniques in Hydroponics

4.2.1 Vertical Farming

A vertical farm comprises the multi-layered cultivation of plants for enhanced yield. It is composed of six structural compo anents to optimize plant growth and appropriate delivery of nutrients. A hydroponics-based delivery system working on the principle of various types of hydroponics as the deep-water culture and nutrient film technique is used for the purpose[34-36]. A balance between growing media, pH, air, and water in the root zone is required for maintaining the optimum growth rate. The nutrient solution is reused by its constant recirculated although this use and reuse of the nutrient solution may substantially alter its composition. This can lead to the complexation of the solution affecting its bioavailability[37-38]. Additionally, this bioavailability will also be affected by the nutrient absorption ratio resulting in changes in nutrient balance[39]. For instance, differential uptake of N by the plants can cause imbalances in the NO3-/NH4+ ratio which can result in phenotypic observations for symptoms of toxicity[40]. Similarly, differential uptake of iron can cause iron deficiency[42]. Such differential uptake of nutrients also influences the antagonistic nutrient reactions like the interference of NaCl in the uptake of NO3- and K+ and inhibition of K+ uptake by NH4+ which further limits nutrient acquisition[41].

A major drawback of nutrient recirculation is the accumulation of phytotoxic organic acids exuded by the roots[42-43]. Activated charcoal technique, slow sand filtration, and electro-degradation techniques are used to remove phytotoxic compounds from the nutrient solution although these techniques are expensive and sometimes inadequate forcing the growers to flush the nutrient solution completely[43]. Furthermore, techniques of disinfection such as hydrogen peroxide, heat, ozone,

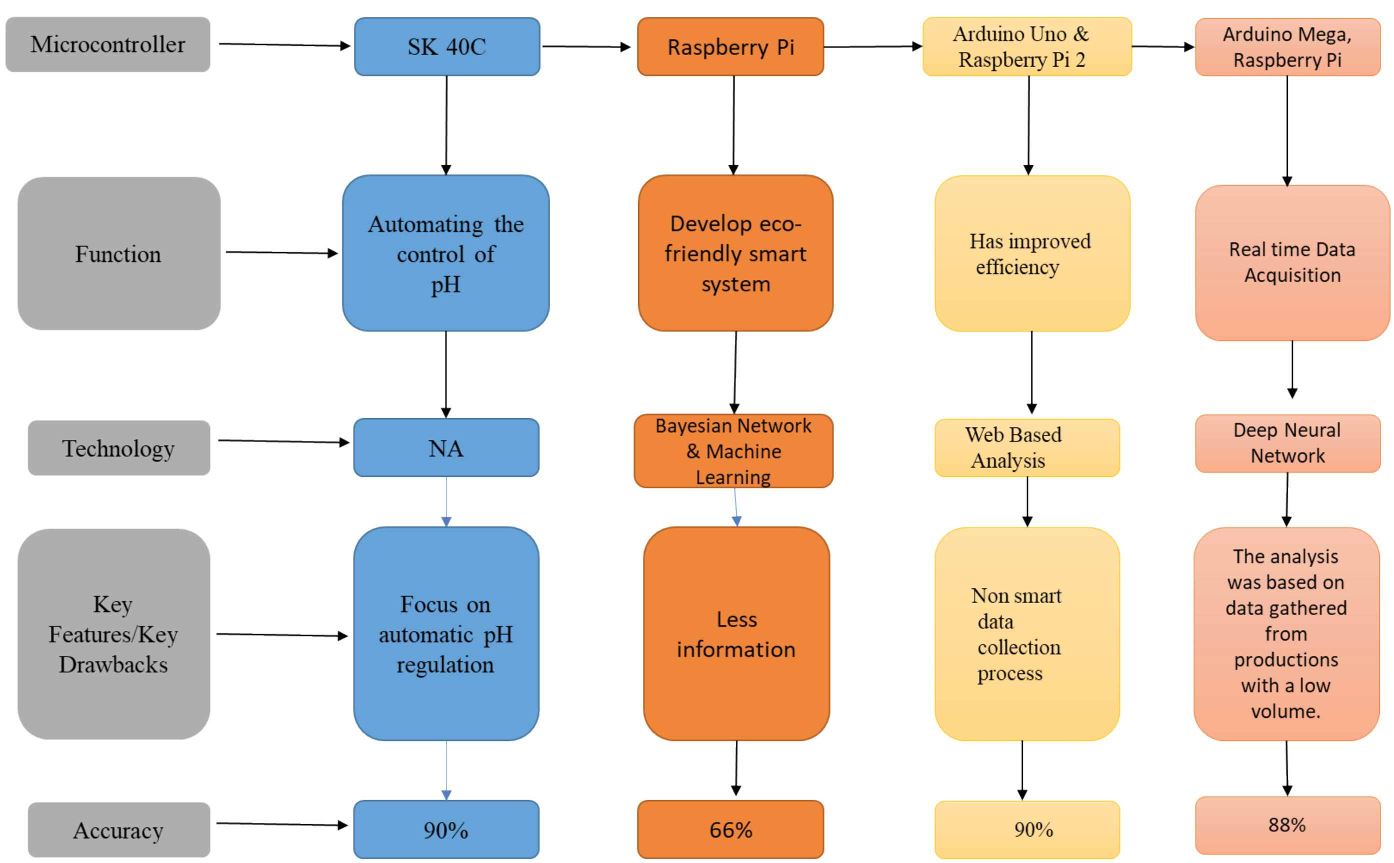

Figure 4. Comparison of various approaches for smart hydroponic systems

and UV radiation are used to control microbial growth which is considerably limited in hydroponics systems as compared to soil-grown plants[44-45]. Although the system of hydroponics is fast developing to accommodate various advancements, its ability to regulate the abiotic factors is of prime importance since these factors primarily govern the development of the plant.

5. ADVANCEMENTS IN THE CONTROL AND REGULATION OF ABIOTIC FACTORS IN THE HYDROPONICS SYSTEM

Abiotic factors include but are not limited to temperature, moisture content, pH, and nutrient availability. Several studies have reported the influence of these factors on the growth and development of plant systems and the importance of regulating the culture conditions, especially in the in-vitro system. The hydroponic system of plant cultivation also requires the proper regulation of these factors based on the requirement of the plant under consideration. Although these factors have been monitored extensively while developing plant-specific hydroponic systems, recent advancements in the control and regulation of these elements have positively affected the growth of the plant in hydroponics. The temperature of the culture system, its moisture content, and light intensity are not directly influenced by the nutrient medium used while the nutrient solution, its pH, conductivity, and salt concentration directly affect the growth of the plants.

5.1 pH

pH of the nutrient solution directly influences the uptake of nutrients by plants since they absorb nutrients by the method of ion exchange. pH in the range of 5.5 to 6.5 is considered to be optimum for most plants. A slight variation in the optimum pH hampers the overall system of nutrient uptake leading to plant death unless the system is changed. It is therefore essential to keep a check on the hydrogen ion concentration of the nutrient solution. Studies have reported the development of certain techniques for monitoring and regulating pH in the system. A technique for automated monitoring of pH specifically for hydroponics systems has been developed by Saaid, *et al* (2020). The pH requirements of the plant are studied followed by the installation of a pH sensor and the setting up of maximum and minimum pH ranges in the sensor. The real-time pH levels are analyzed by the sensor. A syringe pump containing both pH up and pH down solutions drips the required solution as and when the changes in pH are reported[46]. Another study by Rico (2020) on the development of a pH controller for the hydroponic system of lettuce production has positively reported the success of an automated pH controller for monitoring pH[47].

5.2 Electrical Conductivity

Electrical conductivity gives an estimate of the total ionic concentration of the nutrient solution. This information helps in maintaining the soil-like conditions as the pH and nutrient availability required by the plant, are intact. Low electrical conductivity may be indicative of the declining nutrient profile and the need to enhance the same. A high electrical conductivity may be suggestive of salt stress in the plant[48].

5.3 Nutrient solution

Nutrients are the most crucial in the growth and development of the plant. It is therefore important to maintain the appropriate nutrient concentration as required by the plant. The NPK ratio is considered to be the most important besides maintaining the optimum levels of micronutrients and vitamins. A study by Wada (2019) has reported the control of nutrient solution in a hydroponic system of vegetables. The study concerns the utilization of the Yamazaki formula which has reportedly been found successful as a hydroponic nutrient solution in Japan. Various concentrations of this formulation are also available. The electrical conductivity was used as a measure of pH and nutrient concentration in this system for growing lettuce. The nutrient solution was added as per the requirement assessed by the sensors[49].

5.4 Temperature

Temperature has a pivotal role in plant growth and metabolism. Recent studies have explored the role of temperature on plant growth and propagation. A study by Komal *et al* (2014) has reported the use of silicon diode sensors with an accuracy of ±2ºC from -40ºC to +150ºC[50]. A fuzzy logic control design was used for temperature regulation in another study by Erfianto *et al*, 2020. The interpolation method was used to control temperature by identifying the pattern of distribution of heat. This system proved to be effective in controlling temperature as per the requirements of the plant[51]. Similar advancements using techniques such as the Random Forest algorithm are used for monitoring and regulating temperature in real time.

5.5 Oxygen Availability

These factors have been studied individually as well as in combination to study the influence of these factors on plant growth and development. A study by Fuangthong, *et al* in 2018 reported the use of the Fuzzy Logic Control Method to study the cumulative effect of electrical conductivity and pH of the nutrient solution on the growth of green oak lettuce. The results have depicted that this system is efficient to adjust EC and pH as per the requirement of the plants[52].

Another research on the hydroponics growth systems of lettuce, red spinach, and mustard plant pak choy has developed a cumulative group of sensors for assessing the pH, electrical conductivity, temperature of the water and air, and sensor of light using Arduino Uno as the microcontroller. Arduino stores the data and sends it further via a series of steps to the web page on the server. Graphical evaluation of the data was updated regularly after every 10 minutes. The results showed that this automated system of hydroponics system maintenance was efficient in stabilizing the culture conditions for hydroponics thereby maintaining plant growth[53].

Prince, *et al* in 2022 have reported in their study, the development of a novel hydroponic framework capable of remote monitoring. The system consists of sensors for temperature, pH, electrical conductivity, and humidity and is also fitted with an ESP 8266 module. The information of the system can be available on mobile vis the application of cloud computing using Blynk software. The growth of tomato and lettuce in this hydroponic system was used for validating the efficiency of the system over two weeks. Such advancements which involve the use of a cohesive sensor to assess the abiotic conditions of the system while making remote availability of this knowledge possible can further be explored in extensive farming and improving the efficiency in monitoring the hydroponic farms without burdening the cultivator with the same [54].

Hydroponics systems involve the usage of various sensors for monitoring abiotic factors of hydroponics. These sensors together have advanced the maintenance and functioning of hydroponics systems by reducing labour costs and the requirement of skilled staff and hence reducing the chance of error. They have also enhanced control over the system with better yield and higher productivity which was evaluated by the increase in the number of leaves and height of the plant [55-56].

The system of hydroponics has recently been studied extensively as a method of plant propagation commercially. This method has established itself to be a suitable system to grow different plants as per their requirements, in limited spaces and with limited nutrient availability without greatly influencing the commercially and medicinally important phytocompound pool of the plant. This has greatly enhanced the global rate of acceptance of this technique.

6. COMMERCIAL VIABILITY AND ACCEPTANCE OF HYDROPONICS

The agriculture industry is currently under tremendous pressure to meet the growing demands of food crops which has put a positive pressure both on the cultivable land and the need for high-yielding techniques of farming including urban farming and precision farming. Hydroponics is therefore viewed as a suitable alternative solution for food security in the coming years. According to the reports published by Markets and Markets, the market value of hydroponics was USD 9.5 billion in 2020 which has been estimated to grow to USD 17.9 billion at a CAGR of 11.3% by 2026 (Figure 5).

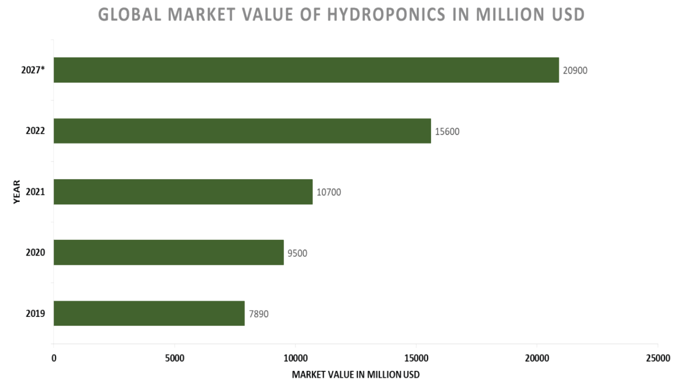

Figure 5. The global market value of hydroponics in million USD from 2019 (7890 million USD) to 2022 (15600 million USD) and its estimated growth by the year 2027 (approximately 21 billion USD)[57].

Hydroponics is currently undergoing major advancements in Europe where countries such as the Netherlands, France, and Spain have extensive cultivations under greenhouses. Advancements in techniques for greenhouse farming have positively influenced the growth of hydroponics in these countries. These reports have been supported by the evaluation of national government statistics which have reported a high acceptance rate in European countries thereby developing the market of this technique[58].

Buehler and Junge reported in 2016 that 9 hydroponic farms were operational in the USA by 2015. These farms worked on the concept of recycling water by harvesting rainwater and reuse of greywater besides chemical-free farming. In threshold countries where the population has significantly shifted from rural to urban in recent times, this form of production holds significant importance[59]. Vertical farming is commonly operational in Holland, South Korea, Canada, Italy, China, the USA, UAE, and the UK although problems with their implementation and acceptance have also been reported[60]. Many crops have been grown in this system as green leafy vegetables, maize, cucumber, microgreens, strawberries, and also certain fungi and lupus. This harvesting system also influences the growth and number of harvests per year as has been observed in the production of leafy greens which increased three-fold in production and the production of strawberries which increased nearly thirty times as compared to open field cultivation.

A study by Eigenbord and Gruda (2015) has reported that by 2010 more than 35000 hectares of urban farms have been employed for the mass production of food in La Habana, Cuba although other countries of Latin America have used this system only for demonstrative purposes [61]. Hydroponics has been employed for the cultivation of cannabis for commercial purposes. Cannabis has been legalized for medical use in many countries as the USA, Spain, Holland, Belgium, Israel, South Africa, Colombia, Mexico, Uruguay, and Canada. Cannabis cultivation requires controlled conditions to attain maximum levels of tetrahydrocannabinol (THC) in the species which is facilitated by hydroponics[62]. The levels of THC can be regulated by monitoring the environmental and nutritional conditions of the plant. The table 4 gives an overview of the different plants grown commercially by hydroponics and their salient features while table 5 gives an overview of these plants along with the Indian and international companies that are the major producers.

Table 5. Indian and International companies growing the plant hydroponically

S.No	Plant	International Company	Indian Company
01	Lettuce	Spread Co., Ltd (Japan) Plenty (USA) Indoor Vertical Farming	Acqua Farms LetcetraAgritech Pvt Ltd.
02	Spinach	Vertical Roots (USA)	Evergreen farms
03	Tomato	Village Farm (USA)	Nature's Miracle
04	Marigold	NA	Gauri-nandan Biotech
05	Rose	Myriad Flowers International	Afforestree

The technique of hydroponics has been well accepted and is being extensively explored for various plants but this method also has certain limitations associated with it.

7. DRAWBACKS AND LOOPHOLES IN HYDROPONICS

Soilless farming is an advantageous technique but it also has prominent limitations. A commercially viable hydroponics system requires high initial financial input besides technical knowledge. Considering that the plants share the same nutrient source, the spread of waterborne diseases is easy[68]. Lack of appropriate oxygen supply and hot climate leads to huge loss of crops. This system also necessitates the maintenance and regulation of pH, EC, and concentration of the circulating nutrient solution. Maintenance of optimum light and source of energy is also required to run the system efficiently[69]. Arduino-based climate control monitor system has been reported to be effective in monitoring environmental conditions such as light intensity, temperature, humidity, and carbon dioxide concentrations[70]. Besides its requirement for the maintenance of abiotic conditions, this system might have a potentially harmful influence on the plant system. Studies have reported the accumulation of nitrate in plant systems.

The system of hydroponics offers various advantages along with certain disadvantages. This system is being explored for its adaptability and ease of maintenance as suggested by various studies. According to a report by Wang, *et al* (2022), the system of hydroponics should be able to support a minimum of 40 large plants as tomatoes, peppers, bananas, and bell peppers besides 72 small plants as strawberries, lettuce, and spinach[71]. Although certain improvisations for some limitations of this technique are currently evaluated, the sustainable and non-polluting nature of this method cannot be ignored which makes this an easy and cost-effective approach for both small-scale and large-scale production.

8. CONCLUSION

The increase in population and decrease in the fertile land for cultivation is putting negative pressure on the cultivation of cash crops leaving less available land for medicinal plants. An assessment of the hydroponics system for the cultivation of medicinal plants and optimization of the same is necessary. Hydroponics and aeroponics

Table 4. Plants grown by hydroponics on the commercial level

S.No	Category	Plant	Feature	Reference
1.	Vegetables	Lettuce	• Short life (>8 crops a year can be harvested) • Good production in NFT • The difference in productivity and nitrate content as compared to soil culture harvest	[59]
2.		Spinach	• Higher percentage yield (97.42%) than geoponic culture (increase in yield by 25%) • 24% increased leaf area, 25% increased plant height than geoponic culture	[60]
3.		Tomato	• A greater yield in hydroponics system (161±6.6 ton per hectare) as compared to open field yield (10.07±0.4 ton per hectare)	[61]
4.	Ornamental Plants	Marigold	• Maximum flowers per plant (23.56) were observed in the NFT system with a maximum flower number of 26.33 • Increased flower diameter in NFT system (8.28 cm) as compared to other soil culture harvest	[62]
5.		Rose	• Minimized chances of disease infestation • Faster growth and cultivation of plant	[63]

are suitable strategies for utilizing the available space and water and nutrient systems effectively. It is now an effective strategy for utilizing space and combating the scarcity of food and fertile agricultural land in third-world countries.

Hydroponics is now being developed rapidly owing to its major advantages. These advantages include water conservation and the efficiency of the system for enhanced output with enriched plant biomass as compared to traditional techniques. This system also surpasses the hindrances of plant tissue culture which has highlighted this technique as a commercially viable solution for plant cultivation. Recent advancements in hydroponics as the inclusion of IoT and sensor-based techniques for automation of hydroponics systems to effectively regulate the plant system also promote the global use of this method. Further studies are required on such automation techniques of hydroponics and research to prove the potency of this method for growing both crops and medicinally important plants.

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CONTRIBUTORS

Mr Utkarsha Srivastava is currently pursuing her doctoral degree in biotechnology from Jaypee Institute of Information Technology, Noida. She completed her Master's dissertation from CSIR-CIMAP, Lucknow. Her interests lie majorly in plant biotechnology, microbiology and bioinformatics.

She has compiled and written the present review under the guidance of her supervisor Dr. Ashwani Mathur. The data has been primarily collected and collated by her for the present work.

Dr Ashwani Mathur has been working as an Associate Professor at Department of Biotechnology, JIIT since December 2010. He is also the Associate Dean (Policy Interfaces and Accreditation). He has done his masters (M.Sc) in Biotechnology from Panjab University, Chandigarh in 2002. He completed his PhD from Department of Biochemical Engineering and Biotechnology, IIT Delhi in 2009. His core area of research includes process optimization for production of different primary and secondary metabolites. He has prior experience of handling microbial, algal, plant and mammalian cells in bioreactor. Currently on-going studies are focused towards development of biosensors for environmental pollutants. Also, the optimization of hydroponic conditions for cultivation of medicinal plant *Bacopa monnieri*, are in progress. The current review has been written under his guidance. He also provided statistical data for the commercial application of hydroponics and also gave insight for the improvement of the manuscript.