***Review Article***

**Hydroponic: A cutting-edge approach to growing high-value crops**

**Abstract**

Hydroponics is an innovative and sustainable agricultural technique that enables the cultivation of high-value crops without soil using nutrient-rich water solutions. This method has gained prominence due to its ability to enhance crop yield, optimize resource utilization and contribute to food security. Hydroponic systems including Nutrient Film Technique (NFT), Deep Water Culture (DWC), aeroponics and aquaponics provide controlled environments that minimize the use of water, pesticides and fertilizers while ensuring faster plant growth and superior nutritional quality. This review explores the characteristics of hydroponic farming the economic viability of high-value crops and the integration of advanced technologies such as artificial intelligence, IoT and precision agriculture. The findings indicate that hydroponics can significantly reduce dependency on arable land, mitigate environmental degradation and support urban agriculture. Despite its advantages, challenges such as high initial investment costs and energy consumption remain key barriers to widespread adoption. With growing global food demands and climate change concerns; hydroponics presents a viable solution for sustainable agriculture. Future advancements in automation and renewable energy integration can further enhance its feasibility. This study underscores the potential of hydroponic farming as a transformative approach to modern agriculture ensuring long-term sustainability and economic profitability.

Keywords Hydroponics, high value crops, aeroponics, farming.

**Introduction**

Rapid global population growth, urbanisation and the depletion of arable land have created the need to explore new farming techniques that result in the high food yields while using the least amount of resources. Of these, hydroponics — the method of using nutrient-rich water solutions instead of soil has proven to be a uniquely popular and effective means of growing plants free of dirt. According to Verma et al. (2024), Hydroponics is a way to grow fruit, vegetables and herbs, particularly in controlled environments such as greenhouses, vertical farms, and urban agriculture environments. The hydroponic system has several advantages, including higher yield, less pesticideuse, efficient nutrient management, etc. According to multiple studies, hydroponic methods can help to improve crop quality, extend growing seasons and reduce dependency on arable land. These make them particularly useful in areas with degraded soil or limited agricultural land (Sharma et al., 2023). According to Singh et al (2023), the hydroponic farming practices also use 90% less water than the traditional farming practices because the nutrient solutions are recycled and reused. Hydroponics is thus a very sustainable method that aligns withworldwide initiativeto help slowing down the climate change and combat issues of food security. The different types of hydroponic systems known include: Nutrient film technique (NFT), Deep water culture (DWC), Aeroponics and Aggregate-based systems. Each has distinct attributes that are well-suited to different crop requirements and environmental conditions (Sujitha & Ashok, 2020). In particular, closed-loop hydroponic systems have attracted interest for their ability to mitigate thedetrimental environmental impacts by increasing resource efficiency and preventing fertilizer run-off (Jain et al., 2025). For higher agricultural yield and sustainability, hydroponics can be integrated with modern technologies such as artificial intelligence  (AI), precision agriculture and smart monitoring systems (Kumar et al, 2024).

Moreover, the issues related to prevention of diseases, nutrients management, and system maintenance require consistent research and development. In order to mitigate these challenges, research and development is currently being conducted to develop scalable and affordable hydroponic systems that can be used in diverse agricultural settings (Wadhwa et al., 2023).The objective of this paper is to give an overview of hydroponic production methods, technological advancement, and the potential for sustainable agriculture. This presentation will provide a real overview of hydroponics as a sustainable agriculture method through conducting literate review and exploration case study. This conversation will be about different hydroponics methods, their applications and how they can contribute to food security globally while promoting eco-friendly sustainability.

**Characteristics and attributes of hydroponics**

In hydroponics, high-value crops grow fast, use fewer resources and give large profits. These characteristics are just simply making them a perfect match with contemporary hydroponic farming, whichever it is a large scale enterprise or small scale urban growers. The selected crops typically exhibit economic viability, consumer interest, and suitability for hydroponic systems. Here are some important features and features of high-value hydroponics crops. High-value crops such as leafy greens, herbs, fruits, and micro greens grow well in hydroponic systems due to the controlled environment that enhances development, nutrition and profitability. These crops are selected based on several factors such as; the market demand, the amount of water and fertilizers utilized the efficiency of growth and the adaptation to hydroponic environment. This article discusses some high-value crops cultivated in hydroponic systems along with their key characteristics.

1. Efficiency of Growth and Productivity

According to Velazquez-Gonzalez et al., (2022) hydroponically farmed, high-value crops are grown faster than in soil, as soil crops compete with each other for nutrients, while hydroponics delivers key nutrients in a balanced solution directly to the root zone. Accordingly, the growth is faster and a shorter cycle from culture to harvest is possible, allowing several harvests per year. Well known for their high-value hydroponic crops, outstanding nutritional quality. Since they can be supplemented with the necessary vitamins, minerals and antioxidants, these crops are more nutrient-dense than their soil-based partners because of the controlled environment in which they are cultivated (Fabek Uher et al., 2023).

1. Adequacy for Regulated Setting

High value crops grown hydroponically in controlled environment such as vertical farming systems, greenhouses and indoor farms. In these controlled environments, the climate outside can fluctuate but production is still possible because these environments are regulated. Hydroponics has a number of benefits over conventional soil-based farming techniques such as the ability to precisely regulate nutrient levels, lower water consumption and the eradication of pests and illnesses that are transmitted through the soil (Sharma et al., 2018).

1. Market Viability and Economic Demand

Hydroponic systems are employed to cultivate high-value crops rated with the best quality and year-round availability and pesticide-free. Hydroponic fruit is a lucrative option for commercial growers because consumers are willing to pay a premium for fresh locally grown food (Rajaseger et al., 2023)

**Hydroponic system of high value crops**

**Table 1. Description of different hydroponic system**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **HYDROPONIC SYSTEM** | **DETAILS** | **SUITABLE CROPS** | **ADVANCEMENT** | **REFERENCES** |
| **Nutrient Film Technique (NFT)** | A thin film of nutrient solution flows over plant roots housed in sloped channels | Lettuce, spinach, strawberries, basil | Efficient water use, continuous nutrient supply, high oxygenation | Jain et al., 2025; Priyanshu et al., 2023 |
| **Deep water culture (DWC)** | Plants are suspended with their roots submerged directly in nutrient-rich water | Lettuce, basil, kale, Swiss chard | Simple setup, rapid growth due to high oxygen and nutrient availability | Kumar et al., 2024; Tan et al., 2023 |
| **Aeroponics** | Roots are suspended in air and intermittently misted with nutrient solutions | Tomatoes, peppers, leafy green | Maximum oxygen exposure, water-efficient, faster growth | Sharma et al., 2023; Wadhwa et al., 2023 |
| **Kratky method** | Passive hydroponic system where plants absorb water and nutrients through a static reservoir | Lettuce, Basil, Cilantro | Low-cost, no need for electricity, easy to maintain | Singh et al., 2023; Verma et al., 2024 |
| **Ebb and Flow (Flood and Drain)** | Plants are periodically flooded with a nutrient solution, which then drains back into a reservoir | Peppers, Herbs, Ornamental flowers | Automated, supports a variety of plant sizes | Priyanshu et al., 2023; Singh et al., 2023 |
| **Aquaponics** | A hybrid system combining hydroponics and aquaculture; fish waste provides nutrients for plants | Leafy greens, Herbs, Strawberries | Sustainable, reduces water waste, produces both plants and fish | Kumar et al., 2024; Tan et al., 2023 |

**Categories of crop grown**

Hydroponics can be done with leafy greens, herbs, fruiting, vegetables, berries, micro greens, root crops and legumes. Quick growth observes in hydroponically grown crops such as kale, lettuce, spinach. Herbs grown hydroponically like cilantro, swiss chard and basil shows high profit.

**Table 2. Categories of different high value crops grown**

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Examples** | **Suggested Systems** | **References** |
| **Herbs and Leafy Greens** | Swiss chard, lettuce, spinach, cilantro, basil, mint | Nutrient Film Technique (NFT): Provides continuous flow of nutrients and oxygen.  Deep Water Culture (DWC): Ensures rapid development and high oxygenation.  Kratky Method: A low-input passive system suitable for home or small-scale production. | Jain et al. (2025), Sharma et al. (2023), Singh et al. (2023) |
| **Producing Fruits** | Cucumbers, eggplants, tomatoes, peppers | Drip Irrigation System: Provides accurate nutrient control for heavy-feeding plants.  Aeroponics: Maximizes oxygenation and nutrient absorption, promoting quicker growth and higher yields. | Kumar et al. (2024), Wadhwa et al. (2023) |
| **Crops with Roots and Tubers** | Potatoes,  beets, radishes, carrots | Ebb and Flow (Flood and Drain) System: Provides aeration and consistent hydration, encouraging root growth.  Drip Irrigation System: Enables precise water and nutrient control, reducing the risk of oversaturation. | Jain et al. (2025), Sharma et al. (2023) |
| **Berries and Strawberries** | Raspberries, blueberries, strawberries | Nutrient Film Technique (NFT): Ensures consistent growth and fruit development.  Aeroponics: Increases oxygen exposure, enhancing berry production and root health. | Singh et al. (2023), Wadhwa et al. (2023) |
| **Medicinal and High-Value Plants** | Cannabis, ginseng, lavender, aloe vera | Aeroponics: Provides optimal oxygen and nutrient absorption, crucial for medicinal plants with specific growing needs. | Kumar et al. (2024) |

**Quality enhancement in high-value crops**

According to Seerat et al. (2020) Global increase in the demand for quality, nutrient-rich crops can be attributed to the need for sustainable agricultural solutions and health-conscious consumer preferences. Traditional farming techniques are vulnerable to unstable soil quality, scarcity of water and climate changes that can adversely affect the quality of crops. Hydroponics allows for accurate control of the environment in which you grow, delivering greater yields with better texture, flavor and nutritional value. Hydroponics has revolutionized contemporary agriculture, greatly enhancing the quality of high-value crops. The precise nutrient delivery, perfect growing environment and controlled growth parameters afforded to plants by hydroponic systems as compared to traditional soil-based agriculture lead to enhanced crop health, taste profile, texture and nutrient density. Leafy greens grown hydroponically, strawberries, tomatoes, herbs and microgreens are some of the high value crops notable increases in quality have been demonstrated (Velazquez-Gonzalez et al., 2022).

Strawberries, a very profit­able hydroponic crop, have improved flavor, larger size and lower pesticide residues. Hutchinson et al. (2025), for example, hydroponically grown strawberry plants receive precise formulations of fertilizer that optimize fruit development that leads to continual enhancement of flavor and texture. The regulated growing environment minimizes exposure to soil-borne diseases, which promotes healthier and more consistent fruit production as well. Tomatoes are another popular hydroponic crop that produces a high-quality fruit as the lycopene content is higher than soil-grown tomatoes and they often have enhanced flavor and more consistent ripening. The concentration of lycopene, an important antioxidant nutrient that provides the health benefits associated with tomatoes is therefore increased due to controlled nutrient management in hydroponic farming Seawright et al (1998).

**Table 3. Improved quality observed in high value crops grown**

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| --- | --- | --- |
| **Crop** | **Quality improvement observed** | **References** |
| **Lettuce** | Precise control of nutrient levels in hydroponic system can improve nutrient quantity and flavor. | (Vikanksha & Singh, 2023) |
| **Basil** | Best yield has been obtained when nutrient concentration maintained at 1100ppm for media of vermiculite | (Rani, 2023) |
| **Tomato** | Lypopene content: Increased 49%. Fructose and Glucose content increased by 30.2% and 33.4% | Seawright et al (1998) |
| **Purslane** | Boron fortification: Increasing B concentration led to a significant elevation (1.8- to 10.7-fold increase).  - **Iron Content**: Increased.  - **Nitrate Content**: Decreased with higher B concentration. | (Chrysargyris et al., 2024) |
| **Strawberries** | **Yield and fruit quality: Higher** yield and improved fruit quality under controlled nutrient management. | (Caruso et al., 2011) |
| **Bell peppers** | **Yield and nutrient content** Optimized hydroponic solutions improve yield and nutrient content. | (Flores-Velazquez et al., 2022) |
| **Cucumber** | Higher yields observed in nutrient film technique (NFT) hydroponic systems compared to conventional methods.  - **Fruit Quality**: Improved fruit quality in NFT hydroponic systems. | (Roosta et al., 2025) |
| **Radish** | - **Root Length**: Approximately 30% longer compared to nitrogen-deficient hydroponic solution.  - **Shoot Length**: Increased by ~16.5% compared to nitrogen-deficient solution. | (Rathore & Nema, 2024) |

**Economic Viability and Market Trends for Fast-Growing Crops**

The demand for sustainable farming practices is driving the increase in the use of hydroponicsystems around the world. Hydroponics is a soilless crop-cultivation technique characterized by controlled environments, increased crop yields and efficient resourceuse etc. Market trends and economic viability of hydroponic farming, however, have not ceased to concern farmers, investors, and legislators.

**The Economic Viability**

Hydroponics systems incur a large capital cost upfront, primarily due to greenhouse building, climate control systems and fertiliser solutions. Importantly, in Greece, a financial assessment of the economic feasibility of a hydroponic tomato greenhouse farm in Greece revealed thatafter 4 years of operation, the system is economically feasible because its internal rate of return (IRR) is great, ensuring long-term profitability (Michalis et al., 2022).

Similar research on the feasibility of a small hydroponic business was conducted in Indonesia. The results confirmed that hydroponic vegetable farming in urban locations is profitable, with a net present value (NPV) of Rp196,307,009, and a benefit-cost ratio of 1.93 (Radhy et al., 2024).Hydroponic gardening is also a very lucrative home-industry venture. Even though premium capital investment is required, hydroponic vegetable production as a home business is a legitimate option, based on its promising long-term return on investment (ROI) (Kholis et al., 2022).

**Profitability and Cost-Benefit Analysis**

Key factors influencing the economic viability of hydroponic farming include:

1. Yielding and Revenue generation: Hydroponic systems have a higher yield per square metre than conventional farming. A Brazilian study showed that a hydroponic farm with a sand-based substrate in a small rural property was profitable, generating even a positive net present value (NPV) under risky scenarios (Souza et al., 2023).
2. Operation Expenses: Hydroponic gardening may be more resource-effective with regard to water and chemical inputs, but energy expenses remain a significant concern. The key factor in any cost-benefit analysis of hydroponic farming is power — used to provide artificial lighting and climate (Mishra et al., 2024).
3. Payback Period: Studies show that most hydroponic farms see break even in three to five years. Unlike traditional agriculture investments, a case study in Indonesia indicated payback periods of approximately three years, which is quite short (Radhy et al.,2024)

**Table 4. Cost benefit analysis**

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| --- | --- | --- | --- | --- | --- | --- |
| **Location** | **Investment cost** | **Annual revenue** | **Cost-benefit ratio** | **Payback period** | **Area of investment** | **Sources** |
| **India** | High (Rs.2,15,00,000 – Rs.3,44,00,000) | High (Rs.1,72,00,000 – Rs.3,01,00,000) | >2.0 | 3-4 years | Large-scale commercial hydroponics with high revenue potential | Mishra et al. (2024) |
| **Greece** | High (Rs.2,58,00,000 –Rs. 4,30,00,000) | High (Rs.1,29,00,000 –Rs. 2,15,00,000) | >1.5 | 4 years | Large-scale hydroponic tomato greenhouse;profitable with controlled costs | Michalis et al. (2022) |
| **Indonesia** | Medium (Rs.8,60,000 –Rs.17,20,000) | Moderate-High (Rs.12,90,000 –Rs.21,50,000) | 1.93 | 3 years | Urban hydroponic vegetable farm; ideal for small-scale entrepreneurs | Radhy et al. (2024) |
| **USA** | High (Rs.25,80,00,000) | High (Rs.1,20,40,00,000) | >1.5 | 4-5 years | Large-scale hydroponic facility with advanced climate control | Hopi Resilience Project (2020) |
| **Indonesia** | Medium (Rs.6,88,000 –Rs.12,90,000) | Moderate (Rs.10,32,000 –Rs.15,48,000) | 1.5 - 1.8 | 3-4 years | Home-based hydroponic business; profitable even in small spaces | Kholis et al. (2022) |
| **Brazil** | Low-Medium (Rs.4,30,000 –Rs.10,32,000) | Moderate (Rs.860,000 –Rs.15,48,000) | >1.5 | 3-5 years | Small rural hydroponic farm; good for farmers transitioning from soil-based farming | Souza et al. (2023) |

**Market Trends for Hydroponic Agriculture**

Owing to increasing consumer demand for locally farmed, fresh and pesticide-free food, hydroponic farming market is increasingly becoming popular. Here are some key trends:

1. Application of IoT and vertical garden technologies

Vertical farming, an advanced form of hydroponics, maximizes space efficiency by growing crops in multiple levels. IoT has introduced automation, enhancing climate control and the management of nutrients at hydroponic farms (Malabadi et al., 2024).

1. Development of Urban and Commercial Hydroponic Farming

In cities with little arable land, the growth of urban agriculture and CEA (controlled-environment agriculture) has led to increased demand for hydroponic farming (Michalis et al., 2022).According to studies (Malabadi et al., 2024), the market for hydroponics is likely to grow at a CAGR(compound annual growth rate)of over 20% from 2021 to 2028.

1. Environmental Benefits and Sustainability

Hydroponic farming advocates sustainability by reducing the use of pesticide, eliminating soil degradation, and using less water (Souza et al., 2023).Certainly, the potential integration of hydroponics into the global agricultural system and its prospected overcome of land usage for food production on a global scale has been proven to be responsive to the issue of food security (Kholis et al. 2022).

**Future Prospects High Value Crop Cultivation**

According to (Bunyuth & Mardy, 2024), 2050, there are expected 9.6 billion population on earth, the demand for food also increases by 70% (United Nations, 2023). With 80% of the world’s arable land already in use, traditional farming practices simply cannot meet the increasing demand for food. Hydroponics, then represents a more viable prospect for developing systems of food production that don’t overstrain water and land. And finally (Rajaseger et al., 2023) Reached to the conclusion that in recent years, advanced on the use of high end technologies. These are AI/Smart, IoThRobics and domotics (smart house). They are also employed in indoor hydroponic production with useful applications. Thanks to the amount of information available and the dozens of ways to grow a farm both indoor and hydroponic cultures are becoming increasingly popular with farmers. Controlled-environment agriculture (CEA) has emerged as a viable method to ensure year-round production in the face of climate change-induced runoff of crop failure. Vertical farms are being adopted to grow high-value crops such as microgreens, herbs and specialty vegetables, as they provide an optimum environment for plant growth despite ambient weather (Beacham et al., 2019). These indoor farming systems utilize some combination of automated watering systems and climate-controlled chambers and LED illumination to maximize photosynthesis and growth efficiency. Despite using less space and water, vertical farming has significantly boosted the productivity and nutritional value of strawberries, basil and leafy greens (D'Imperio et al., 2020). In reaction to the demand for plant-based proteins, legumes, quinoa and chia seeds are increasingly being grown organically and hydroponically. This shift toward high-value functional foods is in keeping with a global movement that seeks to promote dietary choices that are both more sustainable and healthful. Thanks to new technologies and sustainable farming practices, high-value crop production has a bright future ahead, with forecasts of increased output, profitability and resilience to climate challenges. Innovation in hydroponics, vertical farming and precision agriculture is transforming the ways in which key crops including tomatoes, basil, strawberries and medicinal plants are produced year-round and with exceptional quality. As climate change and food security concerns move global agriculture, so firstly investing in high-value crop farming. It is a viable avenue to contribute to food production in a sustainable and profitable ways. Legislative support, outreach, and technical innovation will be crucial to overcoming these hurdles if we are to fully capitalize on the promise of high value crops in the coming decades.

**Conclusion**

A revolutionary development in contemporary agriculture hydroponics provides an effective and sustainable way to grow valuable crops. Innovative farming techniques are more important than ever as the world's population continues to grow and arable land becomes more limited. The effective use of resources is among hydroponics most important benefits. Climate change susceptibility, excessive water use and soil deterioration are common problems in traditional soil-based agriculture. On the other hand, because hydroponic systems have closed-loop nutrient recycling devices, they can consume up to 90% less water.Because of its effectiveness, hydroponics is especially beneficial in areas with limited water resources. Furthermore hydroponics exact control over nutrient delivery guarantees ideal plant growth while lowering the need for chemical pesticides and fertilizers which reduces pollution in the environment. The capacity of hydroponics to yield superior crops with increased nutritional content is another significant advantage. Research has shown that when compared to their soil-grown equivalents, fruits, vegetables and herbs cultivated hydroponically frequently have higher concentrations of vital vitamins, minerals and antioxidantsThe potential of hydroponic farming is further increased by the incorporation of technology. In order to maximize nutrient supply, lighting and climate control contemporary hydroponic systems are progressively integrating artificial intelligence (AI), Internet of Things (IoT) gadgets and smart monitoring systems. Looking ahead, hydroponics is poised to play a crucial role in the future of agriculture. With the global population projected to reach 9.6 billion by 2050, traditional farming alone will not be sufficient to meet food demands. Hydroponic systems with their ability to produce high-value crops efficiently and sustainably provide a scalable solution to food security challenges. By embracing innovation, optimizing resource use and integrating cutting-edge technology hydroponic farming has the potential to revolutionize food production and create a greener more food-secure future.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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