**Evaluation of Crop Diversity in Hydroponic Systems for Maximizing Nutritional Output**

**Abstract**

Hydroponic farming receives increased interest because it effectively uses resources to produce abundant crops. Few studies have explored the relationship between multiple crops grown under hydroponic conditions, and globally they do not represent hydroponic cultivation. This study investigates hydroponic crop diversification by studying the growth patterns together with nutritional characteristics of controlled hydroponic plants. There was analysis of leafy greens and fruiting vegetables along with herbs for determining their nutritional value, production rates and suitability toward hydroponic cultivation. Hydroponics produce superior nutrition quality when vegetative crop varieties are grown together because it fosters greater nutritional content throughout the agricultural system. Further, it was established that integrating multiple hydroponically grown crops in one system represents an important solution to improve nutrition access in areas with limited resources and urban environments.

Keywords: Hydroponics, Crop Diversity, Nutritional Output, Sustainable Agriculture, Food Security

**1. Introduction**

The adoption of hydroponics worldwide continues to rise as people who use land for agriculture choose this method because it offers high output from limited space while using less water, and having better control over environment factors (Thapa, 2024). The absence of soil in hydroponics enables farmers to exercise exact control of nutrient accessibility and factor exposure such as environmental conditions (Sambo et al., 2019). Most hydroponic systems optimize yield for individual crops, yet the assessment of crop diversification benefits in these systems becomes more necessary during present times.

The practice of cultivating multiple plant species serves as a fundamental component for better food availability while increasing the nutritional selection options. The combination of different crops under cultivation strengthens entire ecosystems improves nutrient accessibility, while making resources more efficient (Rajalakshmi, 2022). The global application of hydroponics is constantly increasing, driven by demands for productive agriculture that maximizes yields using minimal resources. Hydroponics, a method of farming produce in nutrient-dense water without soil, is a method of precision control of such environmental variables such as nutrient supply and use of water, a potential alternative to soil farming. The system is of high utility in low arable land or during cases of shortages of water, in that it produces high-quality produce using a high volume of less water—up to 90% compared to soil farming (Gilmour et al., 2019; Chowdhury et al., 2020).

The removal of soil in hydroponics means that growers can control supply of nutrients to their maximum potential to supply to their produce, a process responsible for speeding up their growth rate and produce improvement in quality. Scientific evidence shows that produce that is hydroponically produced tends to exhibit better patterns of growth compared to their counterparts in soil farming, such as higher growth rate and better nutrient use (Solis & Magaret, 2022; Jesse et al., 2019). Lettuce, for instance, has been shown to be growing at a higher rate in hydroponics compared to soil farming systems, a pointer to hydroponics potential in keeping up with food demands around the world (Miller et al., 2020; O'Quinn, 2024). The controlled system of hydroponics also allows year-around cultivation, a promise of food security (Găgeanu et al., 2024).

Despite the various advantages of hydroponics, there is even more appreciation of diversification of crops in such systems. Cultivating multiple varieties of crops is likely to increase food supply and nutrient diversity, more critically in food security matters (Sambo et al., 2019; Guerrero & Barbieri, 2023). Diversification of crops in hydroponics not just increases ecosystem resilience, but also resource use efficacy and accessibility of use of nutrient (Priyanshu et al., 2023). There is little work done in multiple crop hydroponics, and more needs to be done to know various combinations of plants and their effects on total yield of nutrient (Thapa, 2024).

Growth of multiple diverse crops in hydroponics systems has the potential of creating synergisms that lead to higher overall productivity. As a point of example, it is established that cultivation of leafy green crops in combination with fruiting vegetables or herbs maximizes yield and use of nutrient (Xiao, 2024). Interaction of various varieties of plants also minimizes pressures of pests and disease susceptibility, making it a more resilient system (Kumar & Agarwal, 2024). Also, having a capability of designing nutrient solutions that accommodate different crops in respect of their requirements maximizes potential for growth and enhances produce quality (Sapkota et al., 2019). In addition to crop diversification, use of sophisticated technologies such as control systems and monitoring using IoT can be a wonderful means of improving the efficiency of hydroponics. Such technologies facilitate time-sensitive measurement of variables of the environment, nutrient supply, and health of crops, enabling it to accurately adapt to maximum growth (Chowdhury et al., 2020; Niswar, 2024). The use of smart farming in hydroponics can lead to more yields and zero wastage of resources in keeping up with visions of green agriculture (Sagar & Gupta, 2024).

The financial sustainability of hydroponics is also more visible in keeping up with interest in agriculture in cities. Hydroponics is scalable in cities, where there is a lack of sufficient space, and supply produce to consumers in a straight manner without transport fees or carbon footprints (Eduard, 2024). The potential of high yields in small pieces of land makes hydroponics a potential means of growers in cities to produce more using a smaller piece of land (Carroll, 2023). The potential of growing crops in controlled environments also addresses challenges of climate change, ensuring there is a supply regardless of prevailing weather (Găgeanu et al., 2024).

Current research about the operation of multi-crop hydroponic systems is quite sparse. This research investigates how plant selection diversity in hydroponics affects general nutrient production through a comparison of leafy greens to fruiting vegetables and herbal plants.

**Research Objectives**

1. The research investigated the developmental patterns of various hydroponic crops.

2. An assessment of nutrients found in different crops which are grown through hydroponics will be carried out.

3. The evaluation investigated how combining multiple crops in hydroponic systems affects human dietary wellness potentials.

**2. Materials and Methods**

**2.1 Experimental Design**

This research was performed within a regulated hydroponic vegetation growing space that operated under controlled environmental conditions. Three different crop groups were selected, which demonstrated nutritional importance combined with hydroponic compatibility for their evaluation. The selected crop groups were;

(i) Leafy greens (e.g., spinach, kale, lettuce)

(ii) The group of fruting vegetables includes tomato plants as well as bell pepper plants alongside cucumbers.

(iii) Herbs (e.g., basil, mint, parsley)

The research design implemented a complete block arrangement that segmented different crop groups in individual hydroponic channels. The plant roots received constant nutrient solution transportation through implementation of the nutrient film technique (NFT).

**2.2 Nutrient Solution and Growth Conditions**

The maintenance of plant growth required a balanced hydroponic nutrient solution which incorporated major nutrients together with trace elements. Actual conditions for the experiments included:

(i) Temperature:22–26°C

(ii) Humidity: 50–60%

(iii)pH level: 5.5–6.5

(iv) EC (electrical conductivity): 1.2–2.0 mS/cm

The plants received light exposure through LED grow lights during a 14-hour photoperiod.

**2.3 Data Collection**

Information was collected about plant development through assessments of growth and nutritional data at different phases. The following parameters were recorded:

(i) The evaluation of plant growth included measurements for plant height along with biomass data

(ii) Leaf area index (LAI) and yield level (g/m²).

A nutritional analysis utilizing spectrophotometry combined with chromatography methods determined both macronutrient content of protein, carbohydrates, fats and micronutrient chemical content of vitamins and minerals.

**2.4 Statistical Analysis**

The ANOVA analysis method determined the growth performance and nutrient elements between different crop classifications. Tukey’s post hoc test identified statistical differences between groups when p value < 0.05

**3. Results and Discussion**

**3.1 Growth Performance of Hydroponic Crops**

Distinct variations appeared among the diverse crop growth parameters. Leafy greens reached maturity in the shortest time frame of 4–6 weeks. The growth cycles for fruiting vegetables reached between 8 and 12 weeks with higher biomass production results. The growth speed of herbs in hydroponics remained moderate while their compact size made them suitable for vertical farming systems.

Table 1 : Growth Performance of Hydroponic Crops

|  |  |  |  |
| --- | --- | --- | --- |
| **Crop Category**  | **Growth Duration (Weeks)** | **Yield (g/m²)** | **Leaf Area Index (LAI)** |
| Leafy Greens  | 4–6  | | 500–700  | 4.2 ± 0.3  |
| Fruiting Vegetables | 8–12  | 800–1200  | 5.1 ± 0.4  |
| Herbs | 6–8  | 300–500  | 3.8 ± 0.2  |

These results indicate that crop selection should consider both growth duration and space efficiency to maximize output in hydroponic systems.

**3.2 Nutritional Composition of Hydroponically Grown Crops**

Nutrient analysis revealed that each crop category contributed uniquely to dietary needs.

Table 2 : Nutritional Composition of Hydroponically Grown Crops

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Crop Category**  | **Protein (%)** | **Carbohydrates (%)** | **Vitamin C (mg/100g)** | **Iron (mg/100g)** | **Calcium (mg/100g)** |
| Leafy Greens  | 3.5 ± 0.2  | 4.2 ± 0.3  | 45.6 ± 3.2  | | 2.1 ± 0.1  | 120 ± 8  |
| Fruiting Vegetables | 1.8 ± 0.1  | 6.5 ± 0.4  | 28.2 ± 2.5  | 1.3 ± 0.1  | 45 ± 5  |
| Herbs | 4.2 ± 0.3  | 3.8 ± 0.2  | 50.3 ± 4.1  | 2.5 ± 0.2  | 180 ± 10  |

The composition of herbs together with leafy greens showed greater protein amounts in addition to vitamin C, minerals while fruting vegetables presented higher carbohydrate values. Hydroponic systems become more efficient for nutritional output when various types of crops are grown together.

**3.3 Advantages of Crop Diversity in Hydroponics**

Hydroponic systems gain several benefits from cultivating several different crops. They include;

(i) A combination of various crops in hydroponic systems creates nutritional synergy because they provide distinct essential nutrients together.

(ii) Multi-rooted plants take nutrients more efficiently leading to waste reduction in resource management.

(iii) Hydroponic systems that include multiple crops diminish the possibility that pests and diseases will affect specific crops.

(iv) A diverse hydroponic crop yield enables profitable operations because it meets present market needs for fresh nutritious food products.

**3.4 Challenges and Future Considerations**

The implementation of multi-crop hydroponic systems provides multiple benefits but it brings forth the following obstacles:

(i) A crucial challenge exists in properly managing nutrients between different crops grown in the system.

(ii) The requirements for light exposure along with temperature demands differ between various plant species.

(iii) The setup of new crop varieties requires businesses to invest in extra infrastructure to achieve successful operation.

Therefore, research should concentrate on establishing automated systems that manage nutrients efficiently to enhance the practices of multi-crop hydroponic farming.

**4. Conclusion**

Ultimately, the ecological benefits of hydroponics also include conservation of water; it also includes minimized use of pesticides and carbon emission associated with transportation and distribution (Guerrero & Barbieri, 2023). Hydroponics is also going to reuse water and nutrients, thereby making it even more environmentally friendly (Fussy & Papenbrock, 2022). With increasing expansion of the world's population, demand for productive yet environmentally friendly means of food production is going to be even more, making hydroponics a fundamental aspect of agricultural processes in the coming future (Naresh et al., 2024; Găgeanu et al., 2024

Hydroponics face enhanced efficiency in nutritional yield together with sustainably manufactured food through integration of various plant species. Multiple hydroponic crop varieties which include leafy greens and fruiting vegetables and herbs combine to offer key nutrients that serve as an efficient solution for dealing with dietary shortages and food insecurity issues (Jain, 2024). Future studies about automation and optimization methods will enhance the expansion capabilities of varied hydroponic setups.

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**References**

1. Carroll, P. (2023). The comparative performance of soil-based systems with hydroponics. *Agricultural Sciences,* 14(08), 1087-1097. https://doi.org/10.4236/as.2023.148072
2. Chowdhury, M., Khandakar, A., Ahmed, S., Al-Khuzaei, F., Hamdalla, J., Haque, F., … & Al‐Emadi, N. (2020). Design, construction and testing of iot based automated indoor vertical hydroponics farming test-bed in Qatar. *Sensors*, 20(19), 5637. https://doi.org/10.3390/s20195637
3. Eduard, I. (2024). Economic benefits of using an industrial hydroponic multi-tier system. *The American Journal of Agriculture and Biomedical Engineering*, 6(6), 31-37. https://doi.org/10.37547/tajabe/volume06issue06-07
4. Fussy, A. and Papenbrock, J. (2022). An overview of soil and soilless cultivation techniques—chances, challenges and the neglected question of sustainability. *Plants*, 11(9), 1153. https://doi.org/10.3390/plants11091153
5. Gilmour, D., Bazzani, C., Nayga, R., & Snell, H. (2019). Do consumers value hydroponics? implications for organic certification. *Agricultural Economics,* 50(6), 707-721. https://doi.org/10.1111/agec.12519
6. Guerrero, L. and Barbieri, G. (2023). Hydrolab: a module for the investigation of fertigation strategies in hydroponics. *Applied Sciences,* 13(15), 8867. https://doi.org/10.3390/app13158867
7. Găgeanu, I., Tăbărașu, A., Persu, C., Gheorghe, G., Niţu, M., Cujbescu, D., & ANGHELACHE, D. (2024). Hydroponic vertical systems: enhancing climate resilience, water efficiency, and urban agriculture. *Inmateh Agricultural Engineering,* 94-109. https://doi.org/10.35633/inmateh-73-08
8. Jain, S. (2024). Design and implementation of an iot-based automated ec and ph control system in an nft-based hydroponic farm. *Engineering Technology & Applied Science Research,* 14(1), 13078-13081. https://doi.org/10.48084/etasr.6393
9. Jesse, S., Zhang, Y., Margenot, A., & Davidson, P. (2019). Hydroponic lettuce production using treated post-hydrothermal liquefaction wastewater (phw). *Sustainability*, 11(13), 3605. <https://doi.org/10.3390/su11133605>
10. Kailashkumar B., Priyadharshini K., Logapriya M. Hydroponic Cultivation: Factors Affecting Its Success and Efficacy. Int. J.Environ. Clim. Change. [Internet]. 2023 Sep. 6 [cited 2025 Feb. 18];13(10):2403-10. Available from: https://journalijecc.com/index.php/IJECC/article/view/2905
11. Kumar, H. and Agarwal, A. (2024). Comparative study of celery (apium graveolens) on growth, yield and quality under different growing conditions*. The Indian Journal of Agricultural Sciences*, 94(7), 791-794. https://doi.org/10.56093/ijas.v94i7.140506
12. Miller, A., Langenhoven, P., & Nemali, K. (2020). Maximizing productivity of greenhouse-grown hydroponic lettuce during winter. *Hortscience*, 55(12), 1963-1969. https://doi.org/10.21273/hortsci15351-20
13. Naresh, R., Jadav, S., Singh, M., Patel, A., Singh, B., Beese, S., & Pandey, S. (2024). Role of hydroponics in improving water-use efficiency and food security. *International* *Journal of Environment and Climate Change,* 14(2), 608-633. https://doi.org/10.9734/ijecc/2024/v14i23976
14. Niswar, M. (2024). Design and implementation of an automated indoor hydroponic farming system based on the internet of things. *International Journal of Computing and Digital Systems,* 15(1), 337-346. https://doi.org/10.12785/ijcds/150126
15. O'Quinn, A. (2024). Engineering an improved hydroponics system.. https://doi.org/10.21203/rs.3.rs-4736199/v1
16. Rajalakshmi, M., Manoj, V., and Manoj, H. (2022). Comprehensive review of aquaponic, hydroponic, and recirculating aquaculture systems. *Journal of Experimental Biology and Agricultural Sciences,* 10(6), 1266-1289. https://doi.org/10.18006/2022.10(6).1266.1289
17. Sagar, L. and Gupta, R. (2024). Improving agricultural productivity through iot – based hydroponic systems: literature review &amp;amp; prototype study.. https://doi.org/10.21203/rs.3.rs-3889989/v1
18. Sagwal, A., Kaushal, S., & Shubham, S. (2023). Overview of hydroponics towards high quality production of vegetable crops. *International Journal of Plant & Soil Science,* 35(21), 583-591. https://doi.org/10.9734/ijpss/2023/v35i214013
19. Sambo, P., Nicoletto, C., Giro, A., Pii, Y., Valentinuzzi, F., Mimmo, T., & Cesco, S. (2019). Hydroponic solutions for soilless production systems: issues and opportunities in a smart agriculture perspective. *Frontiers in Plant Science,* 10. https://doi.org/10.3389/fpls.2019.00923
20. Sapkota, S., Sapkota, S., & Liu, Z. (2019). Effects of nutrient composition and lettuce cultivar on crop production in hydroponic culture. *Horticulturae*, 5(4), 72. https://doi.org/10.3390/horticulturae5040072
21. Solis, E. and Magaret, J. (2022). Lettuce (lactuca sativa l. var. rincon) production using organic nutrient solution under hydroponics system. *American Journal of Agricultural Science Engineering and Technology,* 6(3), 24-32. <https://doi.org/10.54536/ajaset.v6i3.705>
22. Thapa U, Hansda NN, Kundu S, Giri A, Tamang D, Rahaman AO. Advancements in Hydroponic Systems: A Comprehensive Review. Arch. Curr. Res. Int. [Internet]. 2024 Nov. 16 [cited 2025 Feb. 18];24(11):317-28. Available from: https://journalacri.com/index.php/ACRI/article/view/973
23. Thapa, U. (2024). Advancements in hydroponic systems: a comprehensive review. *Archives of Current Research International,* 24(11), 317-328. https://doi.org/10.9734/acri/2024/v24i11973
24. Xiao, P. (2024). Interactions between crop and microalgae in nutrient utilization in crop-microalgae co-culture. *Bio Web of Conferences,* 111, 01003. https://doi.org/10.1051/bioconf/202411101003