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Sustainable Water Farming with Aquaponics

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Abstract

Aquaponics is an integrated agriculture system that brings aquaculture to the system and fish production together with hydroponics as the plant culture approach. Today, conventional agriculture meets great challenges, such as over-utilization of water, evaporation, and runoff, with over fertilization with chemical fertilizers that degrade soil, pollute water, and diminish biodiversity. Opposite to making agriculture costly and resource-intensive, these form processes toward an environmental conundrum that demands alternative solutions. Aquaponics tries to resolve such a dilemma by providing a sustainable food production system that conserves water, reduces chemical use, and supports plant growth and fish production in a closed-loop system. This project is an attempt to design and construct an aquaponic system that will monitor water quality parameters and plant growth for 12 weeks. The system consisted of a fish tank and a planting area, with water continuously circulated between them so that nutrients will be recycled and balance maintained. Water testing showed that the system maintained an average pH of 6.65, average temperature of 22.47 degrees Celsius, and average ammonia concentration of 0.47 mg/L. The average value for dissolved oxygen amounted to 6.00 mg/L and BOD value stood at 1.71 mg/L, both suitable for the sustenance of aquatic and plant life. Tracking of lettuce development on a weekly basis showed an average growth of 16.86 cm throughout the period. This study holds significance in proving aquaponics as one of the impressively cheap, water-savvy, and environmentally friendly ways of farming. Water savings can be up to 90% compared to conventional methods, growing organic veggies and fishes without using chemical fertilizers, preventing agricultural runoff, and being suitable for urban and small-scale applications. Thus, overall, the study has proven small-scale aquaponics to be a feasible and sustainable method of growing food, thereby bearing potential for commercial scaling in aid of food security and environmental conservation.

1. Introduction

Pollution and global warming are caused by many aspects of resource use, however their environmental repercussions in agriculture get ignored. Conventional agriculture tends to be very water intensive, much of which is wasted because it evaporates, or water cannot be consumed from the soil quickly enough and thus sharing high wastage rates [1]. Moreover, inorganic fertilizers will lead to soil erosion where it gets compacted, and water pollution where the water gets contaminated due to nutrient run-off to surrounding water bodies [2]. Additionally, traditional agriculture is made more expensive by the application of water and fertilizers, heavy equipment, and irrigation systems. The overuse of resources is leading to a rise in carbon emissions that contribute to climate change [3]. All of these are making conventional agriculture another unsustainable phenomenon that is costly to sustain on the horizon.

This study seeks to design sustainable water farming with aquaponics model to respond to these challenges. An aquaponic system integrates aquaculture which is fish farming and hydroponics which is the growing of crops into water or on water to create food in a sustainable way [4]. In such systems, fish waste or effluent is considered as an input for a plant's nutrient which can be viewed as a fertilizer, whereas the plants purify the water meant to be returned to the fish tank [5]. This method conserves space and lowers chemical fertilizers and extra water requirements [6]. Aquaculture and hydroponics rely on water and will be assessed for water quality. Dependent parameters include pH, temperature, ammonia, Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD).

Aquaponics has demonstrated its potential as a sustainable solution for food production due to its ability to produce higher yields with less water and space compared to traditional farming. Studies have shown that aquaponic systems can use up to 90% less water than soil-based agriculture, making them particularly suitable for regions facing water scarcity [7]. Furthermore, integrating aquaponics into urban farming can help mitigate urban heat islands and contribute to local food security, thus lowering carbon footprints associated with long-distance food transport [8]. These systems offer a promising model not only for food security but also for resource efficiency in densely populated or arid environments.

Another advantage of aquaponic systems is the closed-loop nutrient cycling, which reduces the dependency on synthetic fertilizers and minimizes environmental degradation. In conventional agriculture, excess nutrients often leach into water bodies, causing eutrophication and harmful algal blooms [2]. In contrast, aquaponics capture and reuses nutrients, significantly reducing waste discharge. According to Rakocy et al., such systems maintain nutrient equilibrium through biological filtration, where nitrifying bacteria convert ammonia from fish waste into nitrates usable by plants [9]. This self-regulating mechanism supports both aquatic and plant life, demonstrating ecological synergy and promoting environmental stewardship.

Despite these advantages, aquaponics also presents challenges such as system complexity, startup costs, and the need for continuous monitoring. The success of an aquaponics system relies heavily on the balance between fish, plants, and microbial communities. Disruptions in one component can affect the entire system's functionality. Moreover, maintaining optimal water parameters requires regular testing and adjustments to sustain the health of both fish and plants [10]. However, technological advancements in sensors and automation have begun to simplify system management, making aquaponics increasingly accessible for both commercial and small-scale growers [11].

Looking ahead, the scalability and integration of aquaponics into larger food production systems could redefine sustainable agriculture practices globally. Research indicates that hybrid models combining solar energy with aquaponics can further reduce environmental impacts while enhancing energy efficiency [12]. Policymakers and stakeholders should consider investing in aquaponics infrastructure, research, and education to encourage widespread adoption. By bridging the gap between environmental conservation and agricultural productivity, aquaponics holds the promise of a resilient and regenerative food system that aligns with global sustainability goals.

The study's aim is articulated through three main objectives, which collectively establish a clear and attainable vision. This study on sustainable aquaponics aims to address three core objectives, which are designing a sustainable water farming system using aquaponics, testing water quality to evaluate its suitability for both fish and plant species and measuring plant height to assess growth performance within the system. The purpose is to develop an integrated model that combines aquaculture and hydroponics into a self-sustaining, efficient, and environmentally friendly method of food production. By examining water quality, the study evaluates essential parameters such as nutrient content and pH levels, which are critical for maintaining a balanced ecosystem. Measuring plant growth helps determine the productivity of the system and its potential to match or exceed that of conventional agricultural methods. Through experimentation and analysis, this study provides a comparative foundation to understand the strengths and limitations of aquaponics, ultimately contributing to the advancement of sustainable agriculture.

2. Methodology

This section outlines the methods used to design the aquaponic system, manage water quality, and monitor plant growth. It includes the system's structural development using AutoCAD software, procedures for analysing key water parameters like pH, temperature, ammonia concentration, Dissolved Oxygen (DO), and Biochemical Oxygen Demand (BOD) as well as the approach for evaluating lettuce growth performance through regular height measurements. Fig. 1 shows the flowchart of project implementation, highlighting the main steps involved from system design, water analysis, and plant monitoring to data analysis and conclusion.

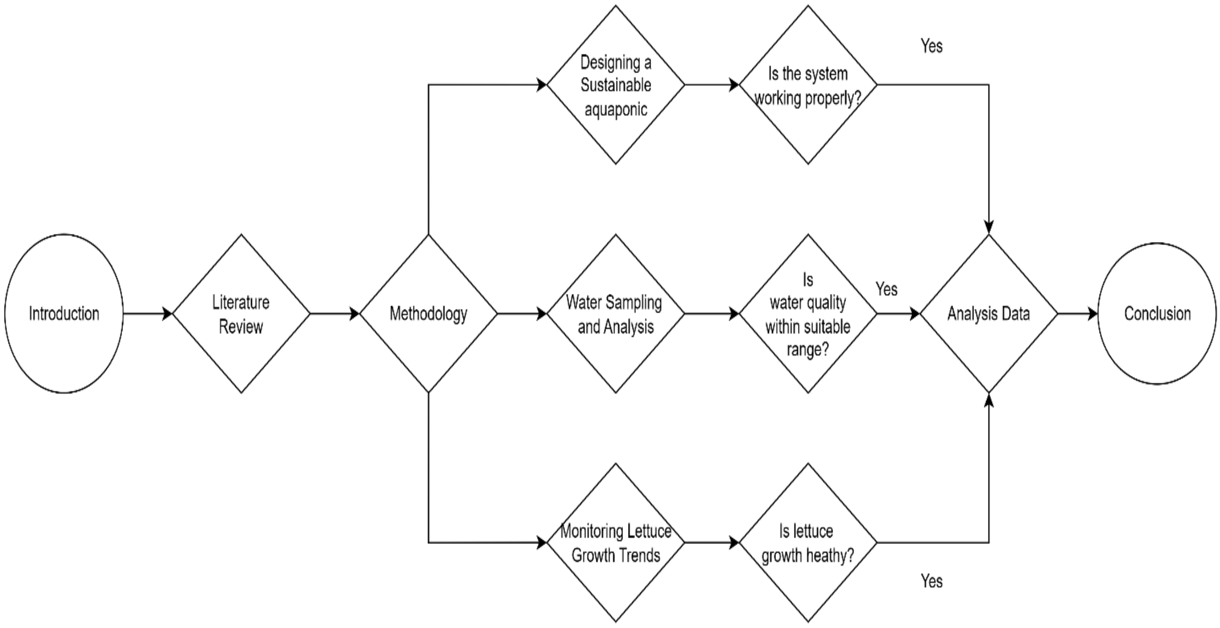
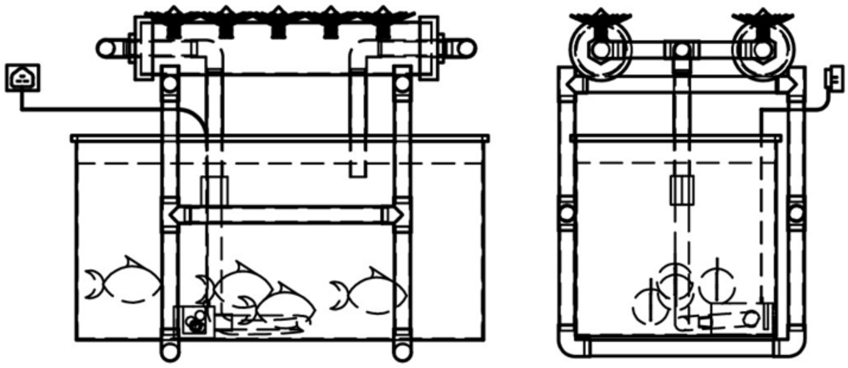


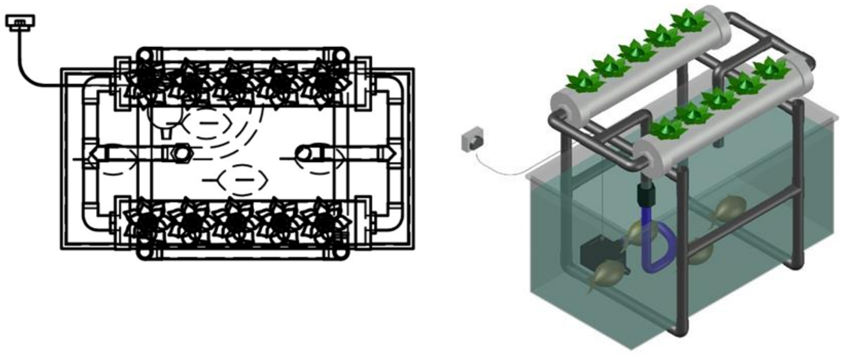
Fig. 1 *Flowchart of project implementation*

2.1 Aquaponic System Design

The design of the Sustainable Water Farming with Aquaponics was developed using AutoCAD software to produce accurate and well-structured system plans. The design comprises front, side, top, and 3D views to illustrate the configuration of main components such as the aquarium and pipes. The 3D model facilitated spatial analysis, optimizing water flow and component alignment to minimize construction errors. The final model dimensions are 600 mm (length) × 600 mm (height) × 400 mm (width), with AutoCAD layers applied for clear separation of each element, enhancing visualization and accuracy. Fig. 2 presents the complete views of the Sustainable Aquaponic System.



(a) **(b)**



(c) (d)

Fig. 2 *Sustainable Water Farming with Aquaponics (a) front view; (b) side view; (c) top view; (d) 3D view*

2.2 Water Quality Management

This aquaponic system's water quality was measured by analysing five most crucial parameters, which is pH, temperature, ammonia level, Dissolved Oxygen (DO), and Biochemical Oxygen Demand (BOD). Water samples were collected from the main aquarium of the aquaponic system and transferred into laboratory beakers before analysis was carried out according to the established standard procedures.

2.2.1 Determination of pH Value

The pH of the water was measured by a hand-held digital pH meter that had been calibrated prior to analysis with standard buffer solutions of 4.0, 7.0, and 10.0 pH. The device used for this measurement was the HACH HQ440d multi-parameter meter, known for its accuracy and reliability in water quality testing. The electrode probe was dipped in the water sample, and the pH was read. pH is significant since it affects the solubility of nutrients as well as the toxicity of ammonia in aquaponic systems.

2.2.2 Measurement of Water Temperature

Water temperature was recorded using a digital thermometer with a sensor probe. The temperature measurement was conducted using the HACH HQ440d multi-parameter meter, which is well-regarded for its precision and dependability in water quality monitoring. The probe was introduced into the sample to obtain an accurate reading of the temperature conditions of the system. This is an important parameter, as it influences fish metabolic rate, plant nutrient acquisition, and microbial activity.

2.2.3 Quantification of Ammonia and Dissolved Oxygen Levels

Sampling of the water in the aquaponic tank was carried out at several points with considerable fish activity and high water flow to obtain representative values using sterilized containers. To ensure ammonia concentration remained within the measurable range of the spectrophotometer, each sample was diluted 50-fold by combining 5 mL of the sample with 45 mL of distilled water. Ammonia concentration was then determined calorimetrically using Nessler reagent at Program 380N, and results were reported in mg/L NH_3-N. Simultaneous analysis of temperature and pH was performed, as these factors influence the ratio between unionized toxic ammonia (NH_3) and the less toxic ammonium ion (NH_4^+). Since unionized ammonia concentrations above 0.02 mg/L are harmful in aquaponic systems, regular monitoring of water quality is essential for sustaining the nitrogen cycle and ensuring the health of fish and plants.

Dissolved oxygen (DO) was measured using a temperature-compensated sensor with a calibrated HACH HQ440d multi-parameter meter, which provides accurate and reliable readings in aquatic systems. The sensor was inserted into representative water samples collected from different locations within the system, and DO levels were expressed in mg/L. This parameter is critical for assessing the availability of oxygen to fish, nitrifying bacteria, and overall system stability.

2.2.4 Biochemical Oxygen Demand (BOD_5) Analysis

The BOD_5 test was conducted to quantify the amount of oxygen consumed in microbial respiration during decomposition of organic matter for five-day incubation. The process was started by employing standard estimation methods to calculate the sample size required. Samples with pH values not in the range 6.0–8.0 were brought to a suitable pH range of 6.5–7.5 using 1 N sodium hydroxide (NaOH) or sulfuric acid (H_2SO_4), depending on the acidity or alkalinity of the sample.

The samples were then filled into 300 mL BOD bottles after adding dilution water. There was a blank bottle, and others contained the diluted samples. Each bottle was then measured for initial DO levels before sealing and incubating in a dark place at 20°C for five days. Final DO measurements were taken after incubation. The BOD_5 value was calculated from the initial and final DO readings. The assay served as an indicator of the concentration of biodegradable organic contaminants within the system.

2.3 Lettuce Growth Monitoring

Monitoring lettuce growth in aquaponic systems is essential to ensure optimal development and efficient nutrient utilization. Regular measurement of plant height offers a simple and cost-effective approach to assess growth performance and detect abnormalities or delays at an early stage [13]. This allows timely intervention to correct issues such as nutrient deficiencies, poor water quality, or environmental stressors [13]. Continuous monitoring also provides data to evaluate system effectiveness, enabling adjustments to feeding rates, lighting, and water flow for improved growth conditions. Additionally, consistent tracking supports accurate harvest planning, contributing to higher yields and more sustainable production [14]. In this study, the growth of lettuce leaves was systematically monitored every four weeks to observe development trends and assess the impact of environmental factors within the aquaponic system. At each interval, plant height was measured from the base of the stem to the tip of the tallest leaf, and observations on leaf color, structure, and density were monitored. This periodic data collection enabled a clear understanding of the plant's growth rate and health over time.

3. Result and Discussion

An analysis was conducted to evaluate the performance of the aquaponic system and the growth of lettuce. The focus includes the aquaponic model design, water quality parameters, and plant growth indicators. The model design shows the internal structure and system layout. Water quality parameters such as pH, temperature, ammonia, biochemical oxygen demand (BOD), and dissolved oxygen (DO) are analyzed to assess environmental stability. Plant growth is measured based on plant height. Data are presented in tables and graphs to show trends, comparisons, and correlations. The analysis helps determine the system's effectiveness in supporting plant growth and overall performance.

3.1 Aquaponic System Physical Model

The set-up consists of a compact aquaponic system developed to illustrate the integration of aquaculture and hydroponics within one workable unit. The system has a clear aquarium with African Catfish (Clarias gariepinus), selected for their hardiness and fast growth [15], whereas the white PVC grow bed is planted with lettuce (*Lactuca sativa*), a crop that requires little nutrients and grows quickly [16]. This ensures that the recycled water is adequately cleaned and reused, providing a better nutrient uptake process that also leads to a sustainable system, where water is reused for fish and plants [17]. The model is cheap, compact, and easy to replicate due to low-cost PVC materials, making it ideal for small-scale farmers, horticulture teachers, and researchers. Fig. 3 shows the front, side, and top views, along with the 3D view of the Sustainable Water Farming with Aquaponic Model.

(a) **(b)**

(c) **(d)**

Fig. 3 *Sustainable Water Farming with Aquaponics Model (a) front view; (b) side view; (c) top view; (d) 3D view*

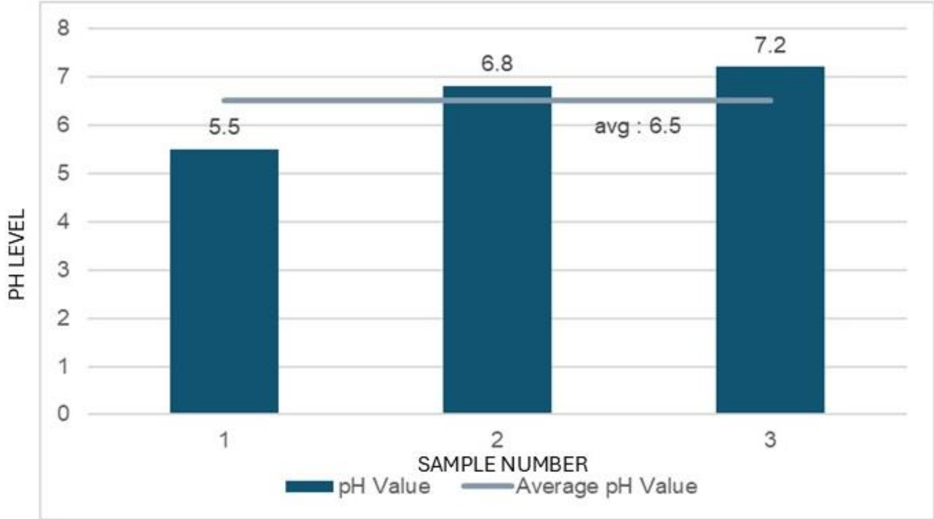
3.2 Water Quality Analysis

Water quality parameters were monitored throughout the research to ensure a suitable environment for both plant and fish growth in the aquaponic system. The recorded water temperature ranged between 21.2°C and 23.0°C, which falls within the optimal range for most freshwater aquaponic species. Dissolved oxygen (DO) levels consistently remained above 5 mg/L, indicating a well-aerated system supportive of healthy aquatic life. The pH values were stable, fluctuating slightly between 6.0 and 7.0, which is ideal for nutrient availability and biological activity within the system. These parameters suggest that the water quality was generally stable and conducive for sustainable aquaponic operation.

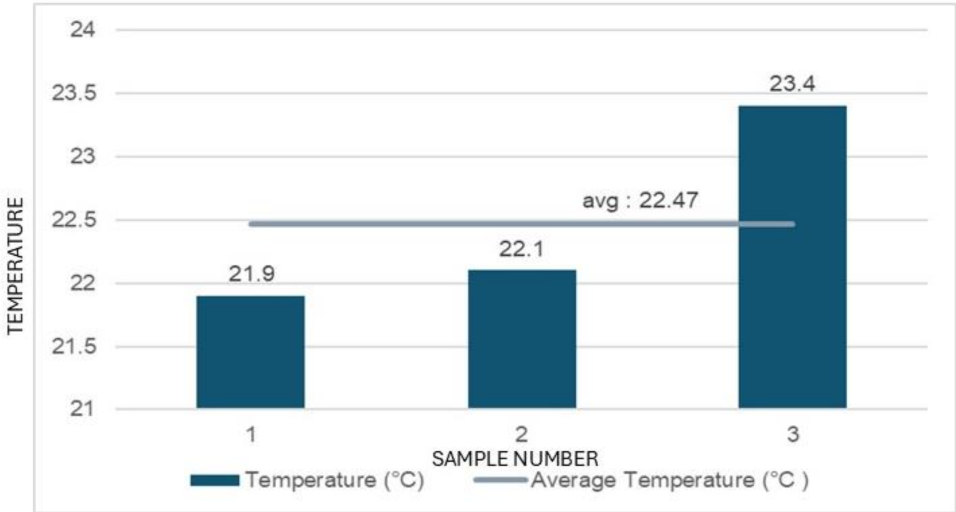
3.2.1 pH Level Analysis and Temperature Analysis

Fig. 4(a) represents the pH values obtained at the experiment's three observations. The average pH value was estimated to be around 6.5, which is in the ideal range of 5.5 to 7.2 for aquaponic systems [18]. A steady pH is very important since any major level change harms the fish or reduces nutrient availability to plants [19]. The system maintained a stable pH throughout the experiment, indicating that catfish are an ideal species for aquaponics, resulting in a healthier environment for fish and plants.

In addition to pH stability, temperature control is also a key factor in ensuring optimal system performance. In the temperature study of the aquaponic system, three readings were recorded 21.90°C, 22.10°C, and 23.40°C as shown in Fig. 4(b). To obtain an accurate thermometer, a calibrated one was employed. The average temperature of 22.47°C suggests that the system operates under stable conditions. Temperatures in aquaponics are important as they affect African catfish metabolism, growth, and health, where the optimal range is between 20°C and 30°C [20], while lettuce growth occurs best at 15°C–25°C [21]. Small variations may have been caused by the time of day, ambient temperature, or heat generated by the pump, but these imply a suitable environment for growth. Hence, making sure of constant temperature monitoring is greatly beneficial for the efficient and sustainable operation of the system.



(a)



(b)

Fig. 4 *Result of (a) pH Level Analysis; (b) Temperature Analysis*

3.2.3 Ammonia Levels Analysis

Ammonia (NH_3-) is the primary nitrogenous waste excreted by fish, originating from the metabolic breakdown of protein in their feed [21]. In aquaponic and recirculating aquaculture systems, un-ionized ammonia (NH_3) is especially hazardous, as it readily diffuses across gill membranes and impairs neural and respiratory function in fish [21]. Ammonia levels reflect the balance between fish metabolic output, biofiltration (conversion by nitrifying bacteria), and plant uptake [22]. Therefore, monitoring ammonia provides crucial insight into the efficiency of the nitrification process and overall system health. Table 1 shows the concentration of the ammonia nitrogen, and its average during the cycle.

Table 1 *Ammoniacal nitrogen concentration of samples*

Sample 2	Sample 3	Average, mg/L NH_3-N
0.47	0.47	0.47

The measured ammonia concentrations were both 0.47 mg/L, averaging 0.47 mg/L. While this is below acute toxicity levels for most freshwater fish, it is slightly elevated for optimal aquaponic performance. Ideally, the ammoniacal nitrogen should stay below 0.50 mg/L to reduce stress and support effective nitrification [23]. Although not critical, these levels warrant monitoring, especially in warmer temperatures where toxic unionized ammonia may increase. The results suggest that biofiltration may not yet be fully efficient, possibly due to a temporary imbalance between fish waste and plant nutrient uptake [23].

3.2.4 Dissolved Oxygen (DO) Analysis

Dissolved oxygen (DO) levels were measured at regular intervals. For aquaponic systems, DO levels should remain above 5.00 mg/L to support healthy aquatic life [24]. The recorded values ranged between 6.64 and 6.66 mg/L, which is within the optimal range. The Fig. 5 shows a slight drop during the second reading that may be due to factors such as temperature changes, excess organic matter, or sedimentation [25]. Despite the decrease, the average DO level remained suitable for the system.

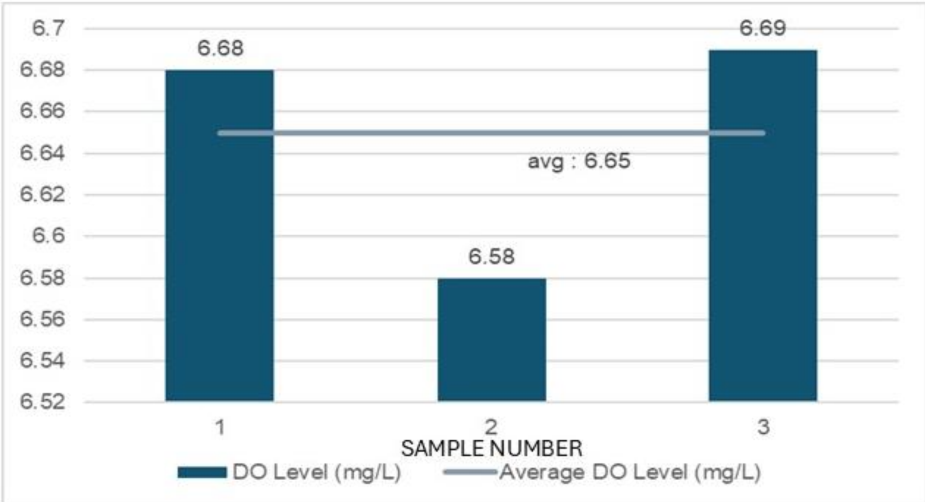


Fig. 5 *DO level results*

3.2.5 Biochemical Oxygen Demand (BOD) Analysis

Biochemical Oxygen Demand (BOD) measures the dissolved oxygen consumed by microorganisms while decomposing organic matter over five days at 20 °C [26]. It indicates the biodegradable portion of organic pollutants and is a key marker of microbial activity and system load. Despite the five-day incubation, the BOD_5 test remains vital for assessing organic waste processing in aquaponic and wastewater systems. In this study, BOD analysis offers insight into the system's capacity to sustain oxygen levels for fish and plant health. Table 2 presents the BOD_5 results using 300 ml sample bottles.

Table 2 *Biochemical Oxygen Demand (BOD) Analysis*

Sample Type	Sample ID	Volume Sample, mL	Dilution factor	Initial DO, mg/L	Final DO, mg/L	DO Depletion, mg/L	BOD, mg/L
BOD	Blank	0	-	8.94	8.39	0.55	-
	1	5	0.017	8.69	8.66	0.03	1.76
	2	6	0.020	8.61	8.56	0.05	2.50
	3	7	0.023	8.54	8.52	0.02	0.87
Average BOD5, mg/L	1.71 mg/L						

The Biochemical Oxygen Demand (BOD) values for the three samples were 1.76 mg/L, 2.50 mg/L, and 0.87 mg/L, averaging 1.71 mg/L. These fall within the low to moderate organic load range, indicating controlled microbial oxygen consumption. BOD levels below 2 mg/L are generally acceptable in well-managed aquaculture systems [27]. However, the 2.50 mg/L reading in Sample 2 slightly exceeds this threshold, possibly due to uneaten feed or poor circulation. While not immediately harmful, it underscores the need for routine monitoring. Overall, the system remains within safe limits, but consistent water quality across all areas should be maintained.

3.3 Lettuce Growth Performance

Lettuce (*Lactuca sativa*) development was observed during a period of 12 weeks, and the measurements of the plant height were made after 4, 8, and 12 weeks to assess the growth in the aquaponic system. During Week 4, a mean height of 3.81 cm was observed, which shows that the early stage of adaptation is in progress as the seedlings started living in nutrient-rich water conditions [28]. At Week 8, the plants grew to a mean of 8.86 cm with significant indications of active vegetative growth with environmental stability like pH, lighting, and the temperature of water [29]. The performance of week 12 also indicated the greatest performance in that the average height was 16.52 cm and there was no sign of deficiency of growth, meaning that the plants were almost ready. Such cumulative outcomes are depicted in Fig. 6 (see Appendix A), which demonstrates the height of the lettuce at every stage and, on average, at all three stages. This continually rising tendency confirms the ability of the system to go ahead with the stable development sustaining the vegetable growing that is not altruistic.

4. Conclusion and Recommendations

This study demonstrated the effectiveness of aquaponics as a sustainable alternative to conventional agriculture by addressing key environmental issues such as excessive water usage, chemical fertilizer dependency, soil degradation, and carbon emissions. The research successfully achieved its objectives: designing a compact and efficient aquaponic system using AutoCAD, monitoring essential water quality parameters (pH, temperature, ammonia, DO, and BOD), and tracking the growth performance of lettuce over 12 weeks. The system maintained stable and optimal water conditions such as an average pH of 6.5 and ammonia concentration of 0.47 mg/L supporting healthy growth for both African catfish and lettuce. Weekly measurements showed steady plant development, indicating that the system effectively nurtured both aquatic and plant life in a closed-loop cycle. This approach not only minimized waste and resource use but also provided a practical solution for small-scale and urban farming. Furthermore, the study highlighted the broader significance of aquaponics in enhancing food security, reducing environmental pollution, and promoting green technology through natural nutrient recycling and space-efficient design. Overall, the findings confirm that aquaponics is a viable, sustainable, and scalable farming method capable of addressing the growing need for environmentally friendly food production systems.

Aquaponic systems can experiment with various plants, such as mustard greens, water spinach, and tomatoes, to name a few, and see which ones grow better and take up more nutrients. Adjustment and nutrient production can be optimized by deploying such aquatic creatures as trout, carp, or hybrid tilapia. It shall be modular in its design to ease maintenance and future upgrading in addition to replacement of components. The water quality can be enhanced with biofilters and sediment traps. It should be studied to get such important parameters as nutrient concentrations, pH, and temperature that can have an impact on the health of the plants. It can be fitted with wheels to aid transportation when filled with water or when it needs maintenance, and a drain outlet at the bottom of the tank can be provided to clean the tank in a short time.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:****Nur Aniss Suraya Ibrahim, Saputeri Saifuddin, Kirtiga Nadarajan, Nor Baizura Hamid, Nornajihah Mohammad Yazid;* ***data collection:*** *Nur Aniss Suraya Ibrahim, Saputeri Saifuddin, Kirtiga Nadarajan;* ***analysis and interpretation of results:*** *Nur Aniss Suraya Ibrahim, Saputeri Saifuddin, Kirtiga Nadarajan;* ***draft manuscript preparation:*** *Nur Aniss Suraya Ibrahim, Saputeri Saifuddin, Kirtiga Nadarajan, Nornajihah Mohammad Yazid, Nor Baizura Hamid. All authors reviewed the results and approved the final version of the manuscript.*

Appendix A

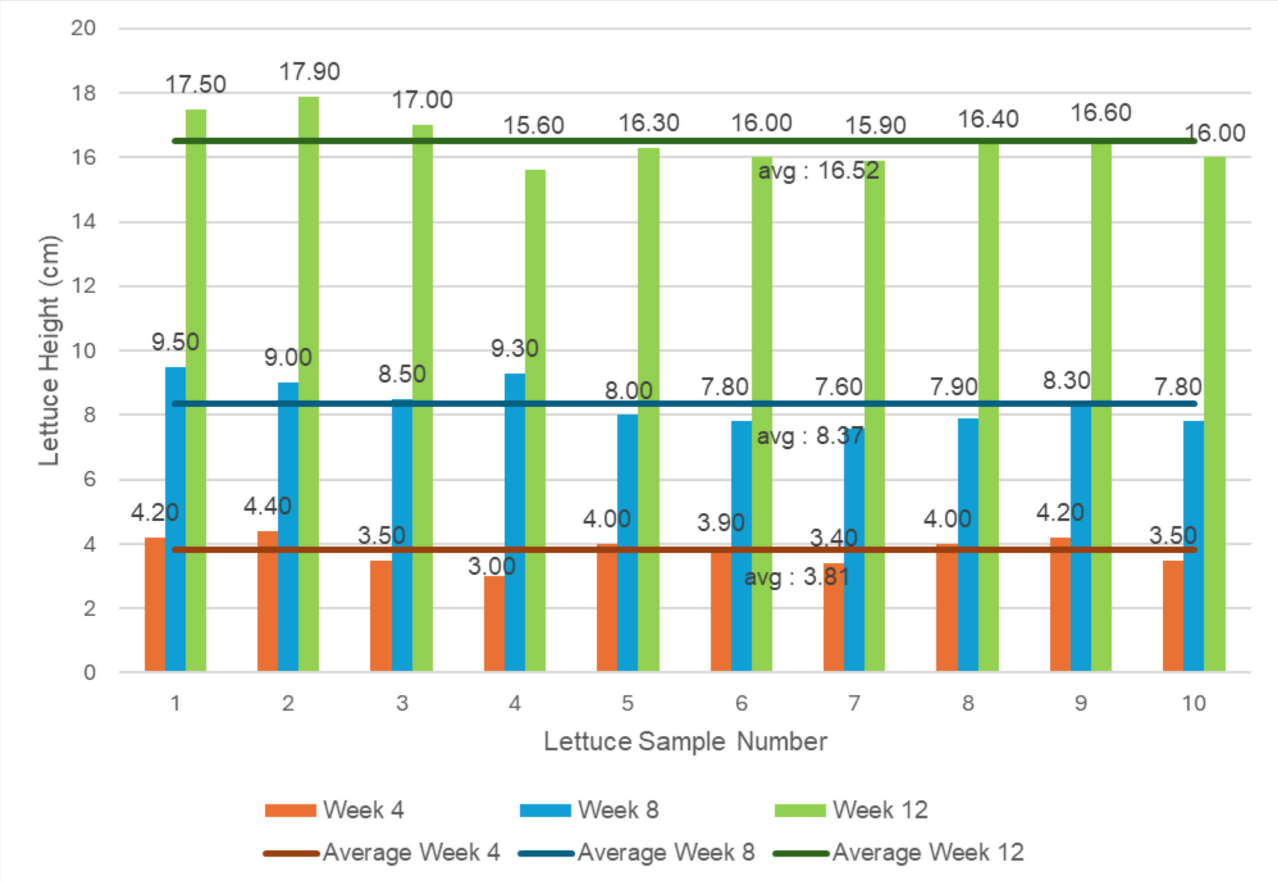

Fig. 6 *Growth performance and average height of lettuce (lactuca sativa) over a 12-week period*

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