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Article

Production performance and profitability of Nile Tilapia (*Oreochromis niloticus*) and water spinach (*Ipomoea aquatica*) in deep water and media bed aquaponics compared to traditional farming

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Abstract: Aquaponics, an integrated system combining hydroponics and aquaculture, has the potential to serve as a sustainable food production method. This study was conducted over 45 days, from July 1, 2019, to August 15, 2019, in Doshaid, a peri-urban area of Savar, Dhaka, Bangladesh, to evaluate the comparative productivity of different aquaponics systems and traditional agriculture. The study assessed the growth performance of tilapia (*Oreochromis niloticus*) and vegetable production in deep water commercial aquaponics, deep-water small-scale aquaponics, and media bed aquaponics, comparing these systems with conventional farming. Additionally, water quality parameters and the benefit-cost ratio (BCR) of the three aquaponics systems were analyzed in comparison to traditional agriculture. Juvenile tilapia, with an initial size of 8.12 ± 1.11 cm and 20.22 ± 0.30 g in deep water commercial aquaponics, 8.15 ± 0.12 cm and 20.35 ± 0.13 g in deep water small-scale aquaponics, and 8.16 ± 0.13 cm and 20.45 ± 0.14 g in media bed aquaponics, were stocked at a density of 100 fish/m³. The fish were fed a commercial floating pellet diet at 5% of their body weight. The highest survival rate and total fish production were observed in deep water commercial aquaponics (90.12 ± 1.40% survival, 7.40 ± 0.10 kg/m³ over 45 days), followed by deep water small-scale aquaponics (85.23 ± 2.15% survival, 6.20 ± 0.10 kg/m³), and media bed aquaponics (80.14 ± 1.40% survival, 5.40 ± 0.10 kg/m³). The feed conversion ratio (FCR) of tilapia was recorded as 1.20 ± 0.15, 1.30 ± 0.12, and 1.40 ± 0.12 for the three systems, respectively. Water spinach yield varied across treatments, with average yields of 1.51 ± 1.12 kg/m², 1.31 ± 1.15 kg/m², 1.65 ± 1.05 kg/m², and 1.80 ± 1.05 kg/m² for different stocking densities (T_1, T_2, T_3, and T_4). The highest vegetable yield was recorded in T_4. Additionally, better gross return, net return, and BCR were observed in T_1, T_2, T_3, and T_4, respectively. These findings suggest that aquaponics, particularly when optimized for stocking density and sustainability, can outperform traditional aquaculture systems in terms of fish production. Aquaponics thus represents a promising and sustainable alternative to conventional aquaculture and agriculture.

Keywords: sustainable agriculture; food security; environmental sustainability; hydroponics; nutrient cycling

1. Introduction

The aquaponics system operates on the principle of utilizing the effluent water generated by fish, which serves as a valuable source of nutrients for plant growth (Nair *et al.*, 2025). The primary production components share access to water and nutrient resources (Okomoda *et al.*, 2023). The fish tank, biofilter, and hydroponic system are interconnected through a water supply (Adriano-Anaya *et al.*, 2022). Aquaponics systems demonstrate significantly higher water use efficiency compared to traditional systems (Alizaeh *et al.*, 2025). Aquaponics, as a sustainable food production technology, has gained worldwide popularity (Ibrahim *et al.*, 2023). By integrating aquaculture and horticulture, it provides farmers and producers with numerous opportunities, such as promoting sustainable agriculture, offering flexible marketing strategies, and creating diverse income streams (Muhie, 2022; Troell *et al.*, 2023).

Bangladesh secured 3rd place in inland water fish production and 5th in aquaculture (Shamsuzzaman *et al.*, 2020). The producers are growing aquaculture horizontally without addressing environmental contamination and land scarcity. In this context, environmental engineering and sustainable agriculture through the Aquaponics System can serve as alternatives to address the issues (Konig *et al.*, 2016; Nair *et al.*, 2025)

As the global population continues to rise, urbanization, industrialization, and climate change are increasingly making farming more difficult. These factors threaten traditional soil-based farming practices, while the amount of arable land available for cultivation decreases due to population growth, development, and the melting of ice caps as a result of global warming. Efficient water resource management is essential for safeguarding communities that are particularly vulnerable to climate-related events, especially in Southwestern Bangladesh (Kopittke *et al.*, 2019; Sheikh *et al.*, 2024). Aquaponics offers a solution by recirculating water, reducing its usage and only requiring replacement when evaporation occurs. Bangladesh's unique geography and complex social and economic conditions make it particularly susceptible to the effects of climate change. By 2050, up to 13.3 million people along the country's coasts may be displaced due to rising sea levels, saltwater intrusion, and other climate-related impacts (Ibrahim *et al.*, 2023). Existing challenges are further exacerbated by natural disasters, such as cyclones, saltwater intrusion, waterlogging, and flooding (Rahman and Rahman, 2015; Akter *et al.*, 2025). In this context, the development of innovative technologies and community-based approaches, such as integrated fish farming, may offer solutions to these challenges and enhance Bangladesh's resilience to climate change (Chowdhury *et al.*, 2022).

Typically, only 30% of the total nutrients delivered to production ponds are converted into aquaculture yield, with the rest accumulating in the pond and often being released as effluents into the environment. Despite this, the essential nutrients for plant growth are present in aquaculture effluent (Ghazali *et al.*, 2024; Tabrett *et al.*, 2024; Achariya *et al.*, 2025). As a result, aquaculture effluents have the potential to benefit agriculture and study found significant improvements in on-farm productivity (up to 10%), water efficiency, and a 28% increase in farmer income when crops were irrigated with aquaculture effluents (Al-Wabel *et al.*, 2024). The world is currently facing several major challenges, including overpopulation, climate change, desertification, water shortages, hunger, and a rise in diseases. One potential solution to these problems is aquaponics, a closed-loop system that integrates hydroponics with aquaculture (Goddek *et al.*, 2015). This environmentally sustainable practice has gained significant attention from various sectors, including agriculture, ecology, and fisheries (Muhie, 2022). The aquaponics production system, which combines hydroponics and recirculating aquaculture, enables the simultaneous cultivation of both plants and fish (Verma *et al.*, 2023).

Conventional farming involves growing crops in soil, outdoors, with irrigation and the application of nutrients. In recent decades, scientists have developed innovative strategies for food production that could help sustainably feed the world's growing population (Javaid *et al.*, 2022). Aquaponics systems offer a potential solution to many of the resource inefficiencies found in traditional agriculture, though the extent of their resource efficiency has yet to be fully quantified in scientific studies (Yep and Zheng, 2019). By using aquaculture waste for agricultural production, aquaponics can reduce water usage and costs, decrease competition for water, lessen the need for chemical fertilizers, and minimize the environmental harm caused by nutrient-rich agricultural runoff in freshwater and marine ecosystems (Ibrahim *et al.*, 2023). The integration of agriculture and aquaculture in Bangladesh holds significant potential for improving livelihoods, particularly in coastal communities.

Conventional irrigation methods often lead to significant water loss through evaporation, runoff, and uneven distribution. These methods aim to improve existing techniques to boost agricultural productivity while conserving water resources and ensuring long-term sustainability in agriculture and water use (Levidow *et al.*, 2014; Ingrao *et al.*, 2023). In the face of growing demand for sustainable solutions, the integration of agriculture and aquaculture has given rise to an innovative technique called aquaponics. This approach not only challenges traditional agricultural practices but also offers a transformative pathway to achieving food sovereignty and improving water efficiency. However, limited research has been conducted on media-based versus traditional aquaponics systems. This study explores the integration of fish and plant production, specifically the cultivation of Nile tilapia (*Oreochromis niloticus*) and water spinach (*Ipomoea aquatica*) within recirculating and aquaponic systems. The research compares fish growth performance and plant productivity between aquaponic and traditional recirculating aquaculture systems.

2. Materials and Methods

2.1. Ethical approval statement

No ethical approval was required to conduct the study.

2.2. Study location and periods

Field trials were conducted in the aquaponics garden at the Centre for Development Innovation and Practices (CIDIP) farm in Ashulia, Dhaka, Bangladesh, from July 1, 2019, to August 15, 2019 (Figure 1). Additionally, the laboratory experiment was carried out in the Aquaponics Laboratory of the Department of Aquaculture at Bangladesh Agricultural University, Mymensingh, Bangladesh.

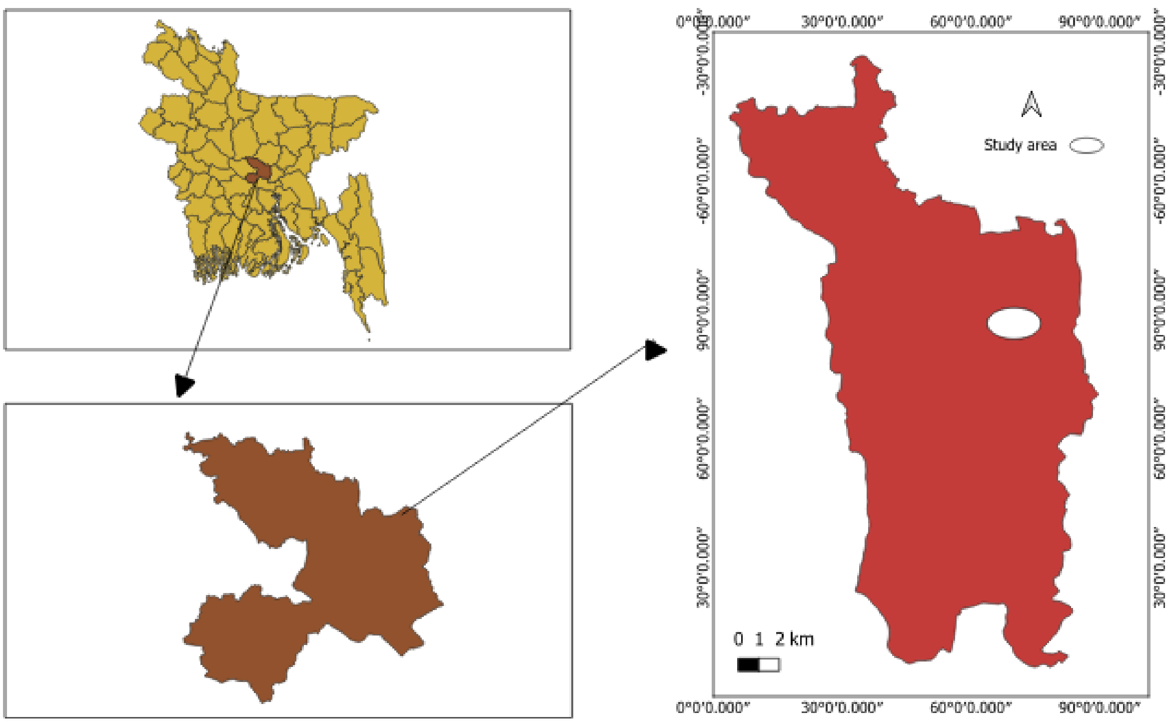

Figure 1. Location of the study area.

2.3. Experimental set-up

The fish rearing tank at the CIDIP farm was constructed using either food-grade plastic or concrete, with dimensions of 1.5 m in height and 3 m in width, and a water capacity of 1000 liters. The vegetable cultivation hydroponic trays were made from galvanized iron (GI) sheets or concrete, measuring 30 m × 1 m × 0.3 m. A GI-sheet biofilter and degassing chamber, with dimensions of 1.5 m × 1 m × 0.5 m, were used for water filtration. Additionally, a concrete sump tank and base tank were constructed, each measuring 1.5 m in height and 1 m in width. PVC pipes were used to interconnect the components of the aquaponics system. The on-farm trial was conducted in the aquaponics garden at CIDIP.

2.4. Experimental design

Various hydroponic systems used in aquaponics offer distinct advantages. The trial was conducted in the field laboratory complex of CIDIP. Eight food-grade plastic or concrete fish rearing tanks, each measuring 1.5 m in height and 3 m in width, were used, with a total water capacity of 10,000 liters. Six vegetable cultivation hydroponic trays, constructed from galvanized iron (GI) sheets or concrete, measured 30 m × 1 m × 0.3 m. Two GI-sheet biofilters and degassing chambers, each measuring 1.5 m × 1 m × 0.5 m, were used for water filtration

(Figure 2). In the deep water culture (DWC) system, plants were grown on floating platforms with their roots submerged in a nutrient solution at a depth of 10 to 30 centimeters, with oxygenation facilitated by circulatory and Venturi systems (Nair *et al.*, 2025). On the other hand, 30 m × 1 m size agricultural land prepared for traditional water spinach farming.

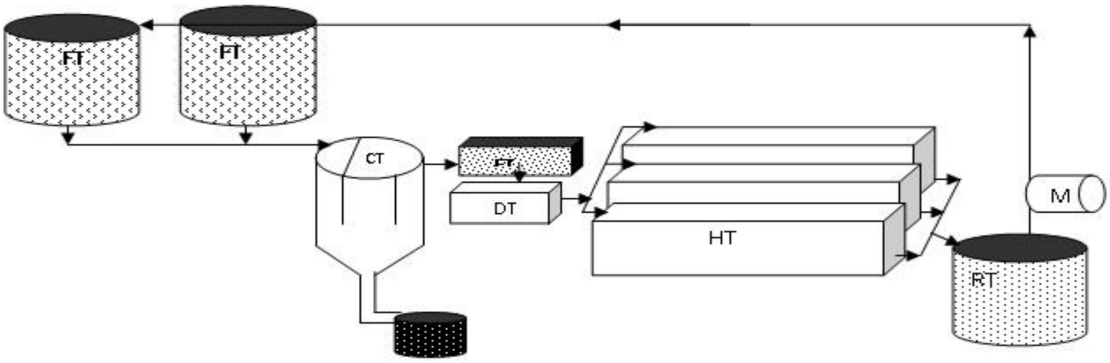

Figure 2. Diagram of commercial deep-water aquaponics (RT=rearing tang, CL= clarifier, FT= filter tanks, DT= degassing tank, HT= hydroponic tanks, B= base addition tank, S= sump).

A concrete sump tank and an additional base tank were constructed, each measuring 1.5 m in height and 1 m in width. PVC pipes were used to interconnect the components of the aquaponics system. Vegetables were cultivated in a media-based aquaponics system using brick chips as the growing medium. In contrast, small-scale deep-water aquaponics systems utilized floating Styrofoam for plant cultivation (Figure 3). In the media-based growing bed (MBGB) system, plants were grown on solid medium beds that provided structural support and filtration, allowing water to flow through the medium to deliver essential nutrients and oxygen (Romano *et al.*, 2022; Nair *et al.*, 2025). The treatment codes and specification for the codes are presented in Table 1.

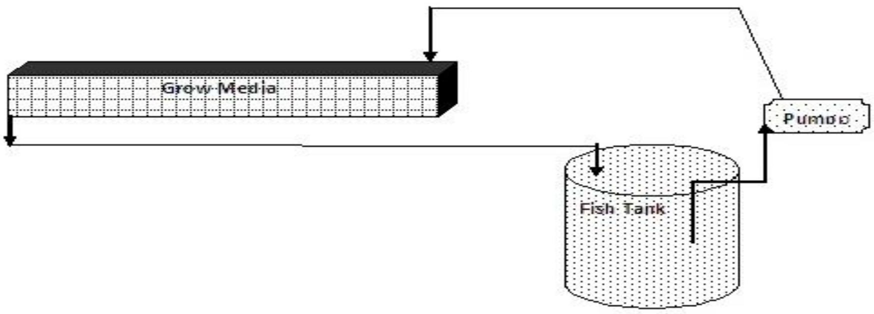

Figure 3. Small scale and media based aquaponics system used in our present study.

Table 1. The study design of the current study.

Treatment code	Treatment specification
T_1	Deep-water commercial aquaponics
T_2	Small-scale deep-water aquaponics
T_3	Media bed aquaponics
T_4	Traditional farming system

2.5. Stocking density and feeding protocol

The experiment was conducted with a stocking density of 100 fingerlings per cubic meter, with each fingerling initially weighing approximately 20 g. Commercially available tilapia feed was used to ensure consistent nutrition. Feeding was administered at 5% of the total body weight, with a frequency of two to three times per day. Throughout the study, key data points were recorded, including initial body weight, fortnightly body weight measurements, mortality rates, and final body weight to assess growth performance and overall health of the fish.

2.6. Sample collection, transportation and acclimatization

Fry of Nile tilapia were collected from the local fish seed market in Mymensingh. The most commonly used method for fry transportation was polythene bags filled with oxygen. For this purpose, a plastic bag with a capacity of 15–18 liters was generally used, containing one-third water and two-thirds oxygen by volume. Approximately 100–125 g of spawn were packed in each bag with five liters of water and 15 liters of oxygen gas. Upon arrival at the pond site, the plastic bags containing the seeds were dipped in water for 10–15 minutes. Tank water was then gradually mixed into the bag until the spawn began to exit slowly into the pond water.

2.7. Feeding rate and methods

In pond, the fish were fed with the experimental diets having 30% protein at the rate of 2 to 6% of body weight for the culture period. The fish was fed two times a day at 09.00 and 17.00 h and the amount of feed was changed or adjusted on the basis of sampling.

2.8. Sampling procedure of fish

Ten to fifteen fish were randomly selected and length (cm), weight (g) will be recorded. Sampling was done at biweekly during the study period. Growth data was analyzed statistically.

2.9. Growth performance and nutrient study parameters

Growth performance is a crucial parameter in nutrient studies. The following metrics were used to assess fish growth: length gain (cm), weight gain (g), percent weight gain, specific growth rate (SGR), feed conversion ratio (FCR), survival rate (%), and fish production (kg/ha).

2.9.1. Length gain

Fish length gain was measured using the following formula,
Length gain (cm) = mean final length (cm) – mean initial length (cm)

2.9.2. Weight gain

Weight gain was calculated using the following formula,
Weight gain (g) = mean final weight (g) – mean initial weight (g)

2.9.3. Percent weight gain

Percent weight gain represents the overall increase in mean body weight over time and was calculated using the formula,
Percent weight gain (%) = [(mean final weight – mean initial weight) / mean initial weight] × 100

2.9.4. Feed Conversion Ratio (FCR)

The FCR is defined as the amount of dry feed required per unit of live weight gain. It was calculated using the formula,
FCR = amount of dry feed (kg) / weight gain (kg)

2.9.5. Survival rate

The survival rate was determined by comparing the number of fish harvested at the end of the experiment with the initial stocking number. It was calculated as follows,
Survival rate (%) = (number of fish harvested / number of fish stocked) × 100

2.9.6. Fish production

Fish production in each treatment was determined by multiplying the mean weight gain of individual fish by the total number of harvested fish. The calculation formula was,
Fish production (kg) = number of fish harvested × mean weight gain (g)

2.10. Statistical analysis

The growth and survival rates of fish were analyzed using a one-way ANOVA to assess significant differences between treatment groups at a $P<0.05$ significance level. All statistical analyses were performed using SPSS version 25.

3. Results and Discussion

3.1. Growth performance of Nile tilapia

The total tilapia production in T_1, T_2, and T_3 was 22.2 kg, 18.6 kg, and 16.2 kg, respectively (Table 2). Correspondingly, feed input to the system was 26.6 kg (T_1), 24.18 kg (T_2), and 22.68 kg (T_3). The local market price for whole tilapia was BDT 120/kg. The FCR for tilapia in this study ranged from 1.2 to 1.4, which falls within the expected range of 1.0 to 2.0 g/day (Rahman *et al.*, 2022). However, an FCR of 1.69 and 1.80 for Nile tilapia in an aquaponics system, which is higher than the values observed in this study (Goada *et al.*, 2015). The total fish yield per cubic meter in T_1, T_2, and T_3 was 7.40 kg/m³, 6.20 kg/m³, and 5.40 kg/m³, respectively. Higher recirculation rates in aquaponic systems resulted in improved plant and fish performance in a study integrating Nile tilapia with various crops over 50 days in a 1 m³ system (Barbosa *et al.*, 2020). Similarly, another study cultured Nile tilapia and Pak Choi using the Root Floating (RAFT) and Dynamic Root Floating (DRFT) techniques for 32 days, starting with an initial stocking density of 2.6 kg/m³. The reported productivity rates were 1.69 kg/m³ and 1.71 kg/m³, respectively, which are comparable to the findings of this study (Silva *et al.*, 2018).

Table 2. Growth and production performance of Nile Tilapia.

Treatment	T_1	T_2	T_3	Significance	CV (%)	*p* value
Stocking density (m^{-3})	100^{a}	100^{a}	100^{a}	NS	2.55	0.23
Initial wt. (g)	20.12 ± 1.20^{a}	20.23 ± 1.20^{a}	20.35 ± 0.13^{a}	NS	1.23	0.35
Initial length (cm)	8.12 ± 1.11^{a}	08.15 ± 0.12^{a}	8.16 ± 0.13^{a}	NS	2.86	0.23
Average final wt.(g)	65.8 ± 3.40^{a}	56.5 ± 3.50^{b}	55.5 ± 3.70^{c}	*	3.45	0.02
ADG (g/day)	1 ± 0.10^{a}	0.80 ± 0.10^{b}	0.78 ± 0.20^{c}	*	4.63	0.01
FCR	1.2 ± 0.15^{a}	1.3 ± 0.13^{b}	1.4 ± 0.12^{c}	*	6.12	0.04
Yield kg m^{-3}	7.40 ± 0.10^{a}	6.20 ± 0.10^{b}	5.40 ± 0.10^{c}	*	5.23	0.02
Survival (%)	90.12 ± 1.40^{a}	85.23 ± 2.15^{b}	80.14 ± 2.22^{c}	*	4.34	0.01

Note: data are expressed as the mean ± SD.* = 5% level of significance; NS = not significant; values bearing different superscripts in the same row vary significantly.

3.2. Growth and production performance of water spinach

The yield of water spinach in T_1, T_2, T_3, and T_4 was 6.13 ± 1.12 kg/m², 1.95 ± 1.15 kg/m², 2.45 ± 1.05 kg/m², and 7.25 ± 1.05 kg/m², respectively, demonstrating satisfactory performance for aquaponic systems (Figure 4). The observed values were found to be suitable for both fish and vegetable production (Sewilam *et al.*, 2022). The fulfillment of nutrient requirements resulted in optimal vegetative growth and maximum production (Knaus and Palm, 2017). Across all experiments, the water quality parameters remained within the suitable range for fish culture, confirming the feasibility of integrating aquaponics for efficient vegetable and fish production.

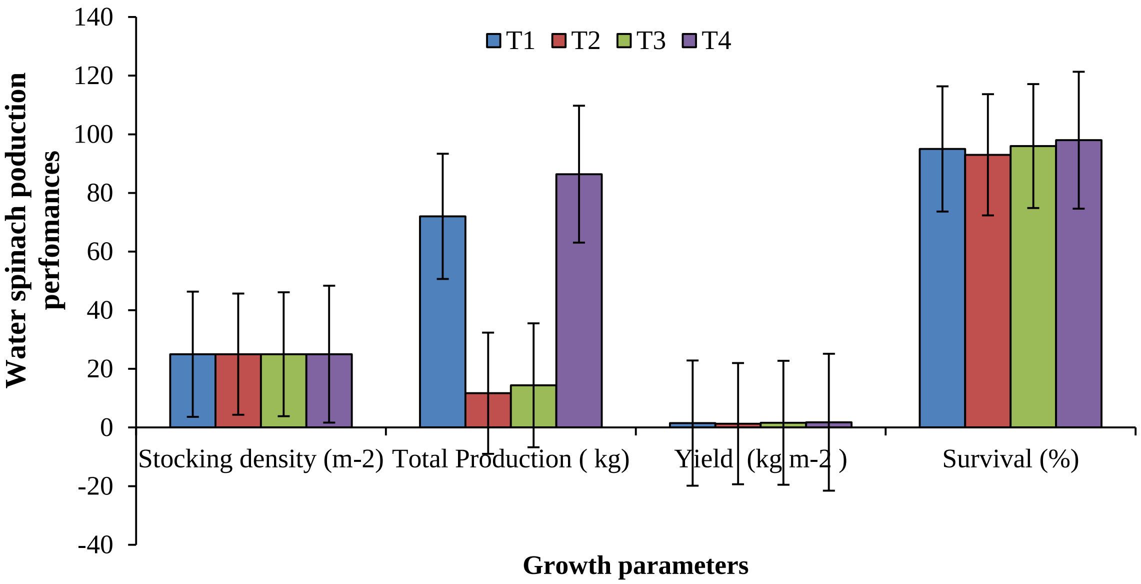

Figure 4. Growth and production performance of water spinach.

3.3. Water quality parameters

The dissolved oxygen (DO) levels recorded were 4.3 mg/L in T_1, 4.4 mg/L in T_2, and 4.5 mg/L in T_3. The pH values were 7.3 in T_1 and 7.0 in both T_2 and T_3. The concentration of nitrite-nitrogen (NO_2-N) was 0.45 mg/L in T_1, 0.135 mg/L in T_2, and 0.56 mg/L in T_3. Ammonia-nitrogen (NH_3-N) remained constant across all treatments at 0.002 mg/L. The electrical conductivity (EC) values were 0.38 mS/cm in T_1, 0.37 mS/cm in T_2, and 0.40 mS/cm in T_3 (Figure 5). In aquaponic system, water quality is one of the most important factors to determine suitable growth of fish and plant species. Maintaining water quality is critical for the sustainability and efficiency of aquaponics systems (Chandramenon *et al.*, 2024). Key parameters that need to be monitored include DO, pH, ammonia, nitrites, nitrates, and phosphates (Yildiz *et al.*, 2017; Gao *et al.*, 2024). Water quality parameter did not show any significant variation throughout the experimental period for the values of culture systems.

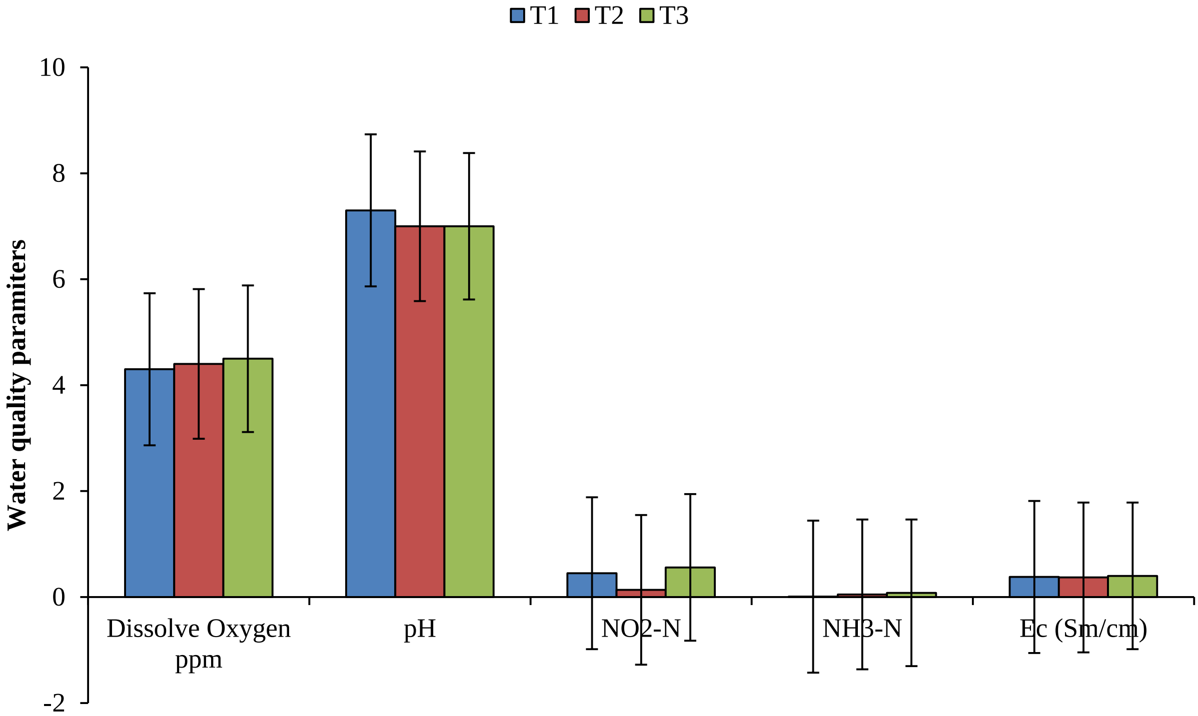

Figure 5. Water quality in different fish tank.

The DO levels in vegetable trays recorded were 3.02 mg/L in T_1, 3.39 mg/L in T_2, and 3.13 mg/L in T_3. The pH values were 7.12 in T_1, 7.00 in T2, and 7.10 in T3. The nitrite-nitrogen (NO_2-N) concentrations were 0.07 mg/L in T_1, 0.06 mg/L in T_2, and 0.05 mg/L in T_3. The ammonia-nitrogen (NH_3-N) levels were 0.001 mg/L in T_1, 0.002 mg/L in T_2, and 0.001 mg/L in T_3. The electrical conductivity (EC) values were 0.35 mS/cm in T_1, 0.33 mS/cm in T_2, and 0.36 mS/cm in T_3 (Figure 6). The observed water quality parameters were within acceptable ranges for aquaponics production. DO levels (3.02–3.39 mg/L) were sufficient for fish and plant growth, while pH (7.00–7.12) remained stable for nutrient uptake. Low NO_2-N (0.05–0.07 mg/L) and NH_3-N (0.001–0.002 mg/L) levels indicated efficient nitrification, preventing toxicity. EC values (0.33–0.36 mS/cm) were optimal for nutrient availability. These results suggest that all treatments maintained suitable conditions for fish and vegetable production, with minor variations likely due to system design and nutrient cycling efficiency (Endut *et al.*, 2009; Hossain *et al.*, 2022; Wang *et al.*, 2023).

4. Economics

The input costs were 700 BDT for T_1, T_2, and T_3, and 120 BDT for T_4 (Figure 7). The overhead costs were 392.67 BDT for T_1, 100 BDT for T_2, 79.17 BDT for T_3, and 12.5 BDT for T_4. The miscellaneous costs were 157.07 BDT for T_1, 40 BDT for T_2, 31.67 BDT for T_3, and 5 BDT for T_4. Gross returns were 2020 BDT for T_1, 1172.5 BDT for T_2, 1080 BDT for T_3, and 150 BDT for T_4. Net returns were 770.27 cccBDT for T_1, 332.5 BDT for T_2, 269.17 BDT for T_3, and 12.5 BDT for T_4. The benefit-cost ratios were 1.62 for T_1, 1.40 for T_2, 1.33 for T_3, and 1.09 for T_4 (Figure 8).

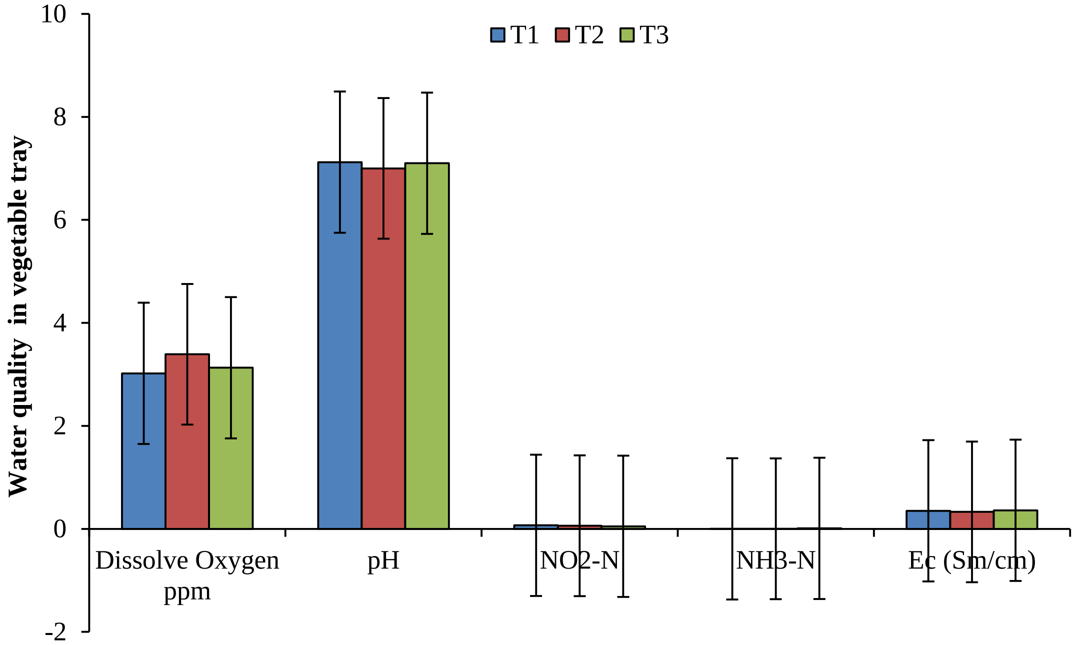

Figure 6. Water quality in different vegetable tray.

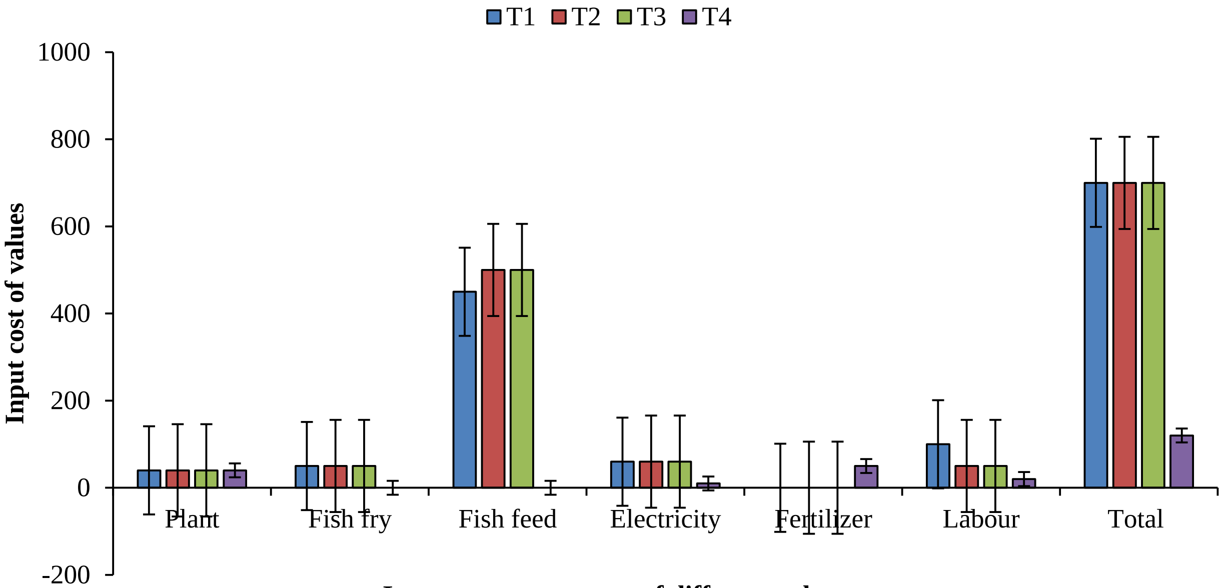

Figure 7. Input cost of aquaponics system.

The cost-benefit analysis of the four treatments (T_1, T_2, T_3, and T_4) revealed that T_1 exhibited the highest net return (770.27 BDT) and the best benefit-cost ratio (1.62), indicating the most profitable outcome. This was followed by T_2 and T_3, with net returns of 332.5 BDT and 269.17 BDT, respectively, and benefit-cost ratios of 1.40 and 1.33, suggesting moderate profitability. In contrast, T_4 had the lowest gross and net returns (150 BDT and 12.5 BDT, respectively) and a benefit-cost ratio of 1.09, indicating the least profitable system. The higher input and overhead costs in treatments T_1, T_2, and T_3 were offset by greater returns, highlighting the economic viability of these systems compared to T_4. These results suggest that while media-based aquaponic systems (T_1,

T_2, T_3) may require higher initial investments, they offer a more favorable economic return, emphasizing their potential for sustainable and profitable food production (Akter *et al.*, 2020). Further research into optimizing costs and scaling systems may improve the profitability of aquaponics, particularly for small-scale operations (Rana *et al.*, 2018; Asciuto *et al.*, 2019; Bablee *et al.*, 2019; Lobillo-Eguíbar *et al.*, 2020).

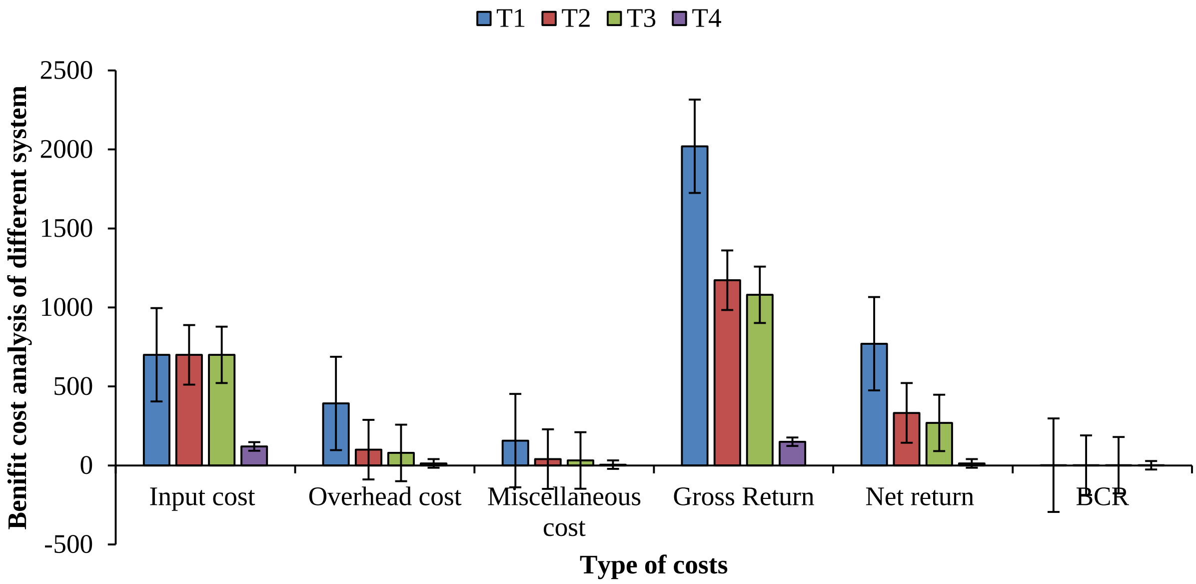

Figure 8. Benefit-cost analysis of Nile tilapia with water spinach (BDT).

5. Conclusions

Aquaponics offers a sustainable solution to global challenges like population growth, climate change, and food security by integrating aquaculture and hydroponics. This system conserves water and recycles nutrients, making it an eco-friendly alternative to traditional agriculture. Various aquaponic systems, such as Deep-Water Culture (DWC), Nutrient Film Technique (NFT), and Media-Based Growing Beds (MGB), each have their own benefits and challenges. This study reveals that media-based aquaponics (T_3) performed the best in terms of fish and plant growth. Further research is needed to assess the long-term viability and profitability of aquaponics as a food production system.

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Data availability

All required data utilized in this study will be provided by the corresponding author upon valid request.

Conflict of interest

None to declare.

Authors' contribution

Md. Rayhan Hossain: preparation of original draft manuscript; Md. Nahiduzzaman: preparation of original draft manuscript and data analysis; Md. Rezwanul Karim: data collection and input data; Md. Tanvir Rahman: writing final manuscript and editing; Md. Abdus Salam: supervision, and writing final manuscript and editing; Md. Shafiqur Rahman: final editing. All authors have read and approved the manuscript.

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