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Original Article

Comparison between Indian spinach production in aquaponics utilizing fish wastewater and hydroponics biogas slurry solution

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Abstract
The experiment compared Indian spinach production in aquaponics utilizing fish wastewater and hydroponics with biogas slurry solution. The aquaponics system involved 60 juvenile tilapias, released into a 750 L tank with an average initial length and weight of 14.41 ± 0.66 cm and 49.81 ± 4.29 g, respectively. The fish were fed commercial pelleted feed twice daily and maintained suitable water quality parameters, including pH, temperature, and DO, within the required range. The hydroponics system used biogas slurry as nutrient media. In each system, 3 plant beds were used, and 4 Indian spinach plants were planted in each bed. Physical parameters of water indicated that the aquaponics system had higher levels of EC, HCO_3, CO_3, Total-N, potassium, sulphur, and sodium than the hydroponics system. After 90 days, aquaponics had the largest plant weight (82.05 ± 23.31 g), with significantly higher levels of nitrogen, potassium, and sulphur content (by 5.54%, 3.10%, and 0.61% respectively) in leaves was found in aquaponics, while the phosphorus (0.85%) was higher in hydroponics. The yield of Indian spinach was higher in aquaponics (2.88 kg m^{-2}) than in hydroponics (1.52 kg m^{-2}). Length gain of experimental fish in aquaponics was 10.54 ± 1.51 cm, weight gain 112.71 ± 21.75 g, with a percent weight gain of 227.23 ± 42.98, specific growth rate of 1.4 ± 0.16% day^{-1}, which was normal. The study concluded that wastes from tilapia aquaponics are more suitable for Indian spinach cultivation than low-cost biogas slurry hydroponics.

Keywords: aquaponics; hydroponics; Indian spinach; production; tilapia

1 | INTRODUCTION

Agricultural lands are shrinking in Bangladesh due to urbanization, industrialization, and other anthropogenic reasons (Rezvi 2018). This problem becomes more complicated as the population is growing rapidly. Fisheries and aquaculture are another sector that plays a major role as a protein source in Bangladesh. Fisheries and aquaculture supply protein to billions of people worldwide and support a significant portion of them for their livelihood. Integrated approaches to produce vegetables and fish at micro to macro levels have great potential. Hydroponics is a system of growing plants without soil and the plants get their nutrients from an aqueous nutrient solution rather than soil which is consist of essential organic or inorganic compounds (Jensen 1999; Asao 2012; Aires 2018). On the other hand, aquaponics is a food production system that integrates hydroponics (the growing of plants in water) with recirculatory aquaculture (the rearing of aquatic animals in tanks, such as fish, crayfish, snails, or prawns) in a mutually beneficial association (Estim *et al*. 2019). The system uses waste water from fish tanks to grow vegetables and herbs hydroponically (Rakocy 1989).

In hydroponics, an aqueous solution of biogas slurry is a feasible and cost-effective nutrient medium (Wang *et al*. 2019; Kang *et al*. 2020; Liang *et al*. 2023). Biogas slurry is a cost-effective substitute for chemical or manure fertilizers because it is organic, has no adverse impacts on the environment, and increases plant productivity (Kumar *et al*. 2015; Basunia *et al*. 2020; Akter *et al*. 2021; Liang *et al*. 2021; Rahaman *et al*. 2021).

In an aquaponic system, the quantity of macro- and micro-nutrients that fish can release into the water for a certain diet must also be balanced; this is heavily dependent on the type of fish, fish density, temperature, and type of plants (Goddek *et al*. 2015). Water is recycled through biological filtration in aquaponics systems, and waste from the fish tank is utilized as nutrition by plants. Bacteria convert ammonia into nitrates, which plants absorb. Filtered water returns to fish tanks through a recirculation process (Bethe *et al*. 2017). For aquaponics, tilapia is a popular fish that is resilient to environmental parameters and produces high ammonia levels while maintaining nutrient levels (Rakocy *et al*. 1997; Rakocy *et al*. 2004; Bishop *et al*. 2009; Salam *et al*. 2014; Azad *et al*. 2018). It is easily cultured in closed systems like tanks (DeLong *et al*. 2009; Johanson 2009). Furthermore, tilapia has a strong food conversion rate and grows quickly (Romana-Eguia *et al*. 2013; Hossain *et al*. 2017; Omasaki *et al*. 2017).

Using an aquaponics system, it is possible to grow various vegetables such as okra (Salam *et al*. 2013; Azad *et al*. 2018); water spinach (Bethe *et al*. 2017); tomato (Salam *et al*. 2014); capsicum, lettuce (Rakocy *et al*. 1997; Pantanella *et al*. 2012; Subramanian 2020); cucumber (Subramanian 2020); cabbage, carrots and Indian spinach (Hossain *et al*. 2022); and broccoli (Nadia *et al*. 2020). Indian spinach (*Basella alba*) is a popular leafy vegetable with high nutritional value and medicinal benefits (Kumar 2013; Singh *et al*. 2018; Ramaiyan *et al*. 2020). This leafy vegetable can be produced through both aquaponics (Shete *et al*. 2013) and hydroponics systems. The difference between typical spinach and Indian spinach is that it can be consumed in both cooked and raw salads (Kumar 2021). The growth potential of Indian spinach is similar in both systems (Atique *et al*. 2022), making it an excellent candidate for both aquaponic and hydroponic culture (Acharya *et al*. 2021; Hossain *et al*. 2022).

Technically, hydroponics systems contain a higher nutrient load for plants than aquaponics (Pantanella *et al*. 2012). But low-cost biogas slurry partially supplies nutrients in a hydroponics system (Wang *et al*. 2019). Sayara *et al*. (2016) reported that nutrients derived from fish waste do not provide the same levels of N, P, K, S, Ca, Mg, and Fe as those supplied in hydroponic solutions. But unused fish food can add some nutrients to the system. In hydroponics, a low-cost nutrient solution can be a good option for a profitable return. Different studies reported yield and quality separately (Acharya *et al*. 2021), but no study compared between aquaponics system and a low-cost biogas slurry hydroponics system. In this study, we tried to compare the growth, production of Indian spinach, physico-chemical parameters of water, and nutrient content in leaves between aquaponics and low-cost hydroponics systems.

2 | METHODOLOGY

2.1 Study area and duration

The present experiment was conducted for a period of 14 weeks (from 19th May to 5th September) at the Aquaponics Laboratory of the Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh, Bangladesh.

2.2 Experimental design

In this experiment, both aquaponics and hydroponics systems were used. The experimental design comprises a fish holding tank, a drum half-filled with biogas slurry solution, plastic pipes, and jerry cans. Six plastic jerry cans were used to plant Indian spinach in two different treatments (T_1: Aquaponics and T_2: Hydroponics) with three replicates each (T_1R_1, T_1R_2, T_1R_3, T_2R_1, T_2R_2, T_2R_3; Figure 1). Plastic jerry canes were used as plant bed where brick lets were used as medium rather than soil (Salam *et al*. 2014; Akter *et al*. 2018).

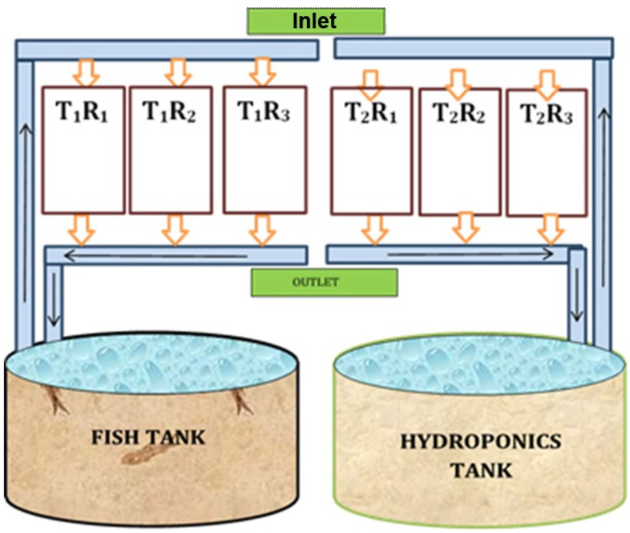

FIGURE 1 Experimental design of the study.

2.3 Aquaponics system

2.3.1 Fish tank preparation

A 750-liter (0.46 m^3) plastic water tank was purchased from a local market. After cutting, cleaning, and liming, 3.5 feet long inlet and outlet pipes were added. The tank bottom was filled with 7.6 cm of gravel (Rakocy 2012). To filter water, a plastic bowl with a 25-watt submersible pump was used. The plastic bowl was covered with a fine meshed net and placed on the upper side of the tank. Four air stones with two 10-watt air pumps were placed in the fish tank for aeration. Clean water was supplied from an overhead tank.

2.3.2 Fish stocking and feeding, and sampling

A total of 60 healthy, disease-free tilapia fry from a previous lab aquaponics experiment were stocked in the aquaponics fish tank on June 5, 2023, with a density of 80 fish / 1000-L (Akter *et al*. 2018). Fishes were disinfected and acclimatized for 3 days before stocking. Commercial floating feed with 30% protein was used in the experiment and supplied twice daily at 3% of fish's body weight. Overfeeding was avoided as extra feed can deteriorate the water quality. The fish sampling was conducted biweekly. Ten fish were randomly caught from the tank, measured for length and weight, and again released into the tank.

2.3.3 Fish growth performance

Randomly selected 10 fish were sampled twice a month to estimate the fish growth in the aquaponics fish tank. According to Akter *et al*. 2018; Bethe *et al*. 2017 calculation of fish growth performance was done employing the following formulas:

Length gain (cm) = Mean final length (cm) – Mean initial length (cm);

Weight gain (g) = Mean final weight (g) – Mean initial weight (g);

Percent weight gain = (Mean final weight (g) – Mean initial weight (g)) / (Mean initial weight (g)) × 100;

Daily weight gain (g) = (Weight gain (g)) / (Duration of experiment);

Specific growth rate (SGR) = ((Log_eW_2 – Log_eW_1) / T2 – T1) × 100; here, W_2 = mean final weight (g), W_1 = mean initial weight (g), and T_2 - T_1 = the duration of the experimental period.

Food conversion ratio (FCR) = Amount of feed (kg) / Weight gain (kg);

Condition factor = body weight / $Length^3$;

Survival rate = (Number of fish harvested) / (Number of fish stocked) × 100;

Fish production = Number of fish harvested × mean increased weight.

2.4 Hydroponics system

2.4.1 Tank preparation

The hydroponic tank was different from the aquaponic tank. A 0.11 m^3 plastic barrel filled with water and equipped with a 12-watt pump was used to store the biogas slurry solution (Akter *et al*. 2018). The drum was filled with biogas slurry once a week.

2.4.2 Collection of biogas slurry and preparation of biogas slurry solution

Biogas slurry was collected in a 0.04 m^3 plastic container from the biogas plant of Cattle Farm, Animal Science Department, Bangladesh Agricultural University, Mymensingh. The biogas slurry solution was added to the drum weekly, filling half of the drum. Each time, the prepared biogas-slurry was diluted with distilled water after screening (to remove the large particles) and soaking overnight to prevent clogging during the flow of the solution through the pipe (Liu *et al*. 2011).

2.5 Vegetable bed preparation, planting, and watering

A total of six plastic food-grade jerry cans (Nadia *et al*. 2020) were used; three in each of aquaponics and hydroponics for Indian spinach culture. Food-grade jerry cans are locally available, affordable, and high in quality. The canes, measuring 44×35×14 cm^3 (0.02156 m^3), were cut into pore-shaped outlets for re-circulating water, cleaned and sun-dried, filled with bricklets, and set on a bed with 3.5 ft long inlet pipes. The surface area of each bed was 0.154 m^2. Indian spinach seedlings were germinated in soil from locally purchased seeds and planted in grow beds. Each bed had four seedlings planted in its corners. The total number of seedlings was 24. They were watered three times daily with fish tank water in aquaponics and biogas slurry in hydroponics, using porous PVC pipes and submersible pumps. No chemical fertilizer was added, and the pipe was cleaned weekly to ensure maximum water supply.

2.6 Sampling of Indian spinach for growth performance

Indian spinach was sampled bi-weekly and harvested monthly from both culture systems (Akter *et al*. 2018; Salam *et al*. 2020). The plant's height, leaf number, leaf length, width, plant weight, root weight, and dry weight of the plant were recorded. Height of plants, number of leaves, length, and width of leaves were measured biweekly using a measuring scale. Leaf width was measured from average of three parts of that leaf. The plant's weight and root weight were measured during harvesting using an electric balance monthly. After harvesting, the plants were dried in an oven overnight, and the dry weight was measured using a precision balance. Using those data growth of Indian spinach were measured.

2.7 Leaf analysis

Leaf samples were analyzed to observe nutrient levels in aquaponics and hydroponics systems. Samples were dried, labelled, and taken to the Humboldt Soil Testing Laboratory at Bangladesh Agricultural University for laboratory analysis. Percent of nitrogen was analyzed using Kjeldahl method (Sunagar *et al*. 2014), potassium was analyzed by flame atomic emission spectrophotometer, phosphorus, and sulphur were measured following (Wolf 1982).

2.8 Physico-chemical parameters of the fish aquaponic tank water and hydroponics

Tank water from both aquaponics and hydroponics systems was sampled fortnightly between 8.30 am and 9.30 in each sampling date and refrigerated at 4°C in labeled plastic bottles for chemical analysis. Dissolved oxygen (DO), temperature, pH, and electric conductivity (EC) were measured using a multiparameter (HANNA-HI-98194). Sulphur (S) concentration was determined using Na_3Br oxidation method (Tabatabai and Bremner 1970); CO_3 and HCO_3 was measured using standard titration method (Richard 1954); sodium (Na) concertation was measured using a salt refractometer; total nitrogen (Total-N), nitrite (NO_2-N), nitrate (NO_3-N), total phosphorus (TP) and potassium (K) were measured using a Hach DR4000 spectrophotometer following salicylate, diazotization, cadmium reduction, ascorbic acid, acid persulfate digestion, tetraphenylborate method respectively. All analyses were done at the Humboldt Soil Testing Laboratory, Bangladesh Agricultural University. The mean differences between influent and effluent in aquaponics and hydroponics systems were calculated by subtracting the influent from the effluent. The differences were compared statistically to detect significant differences in physicochemical characteristics.

2.9 Data analysis

After sampling, datasets were prepared using Microsoft Excel 2021. All descriptive analysis, statistical tests and visualization were performed using GraphPad Prism for Windows (2024). Fish growth was demonstrated through a linear regression analysis of sampling days, total length, and body weight. To compare physicochemical parameters and plant growth, an unpaired *t*-tests with Welch's correction was performed. The changes of physicochemical parameters between effluents and influents in two groups were compared using Multiple unpaired t-test followed by Holm-Šídák multiple comparison.

3 | RESULTS

3.1 Water quality parameters of the fish tank

Water quality parameters, including pH, temperature, and dissolved oxygen, are crucial for fish growth and survival, and their maintenance is essential for culturing organisms (Jana and Sarkar 2005; Verma *et al*. 2022). Table 1 represents the water quality parameters of the aquaponics fish tank observed during the study period.

3.2 Physicochemical parameters of influent and effluent in aquaponics and hydroponics systems

The levels of water quality parameters in the influent and effluent of aquaponics and hydroponics systems, including pH, electric conductivity (EC), carbonate (CO_3), hydrogen carbonate (HCO_3), total nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and sodium (Na) presented in Table 2 and Table 3.

In July, aquaponics effluent showed significantly ($p < 0.05$) lower levels of EC (338 ± 11.00 µS cm^{-1}), CO_3 (18 ± 4.31 ppm), and phosphorus (0.50 ± 0.11 ppm) compared to influent. The levels of HCO_3 (237.90 ± 7.21 ppm) and total-N (7.00 ± 0.7 ppm) in effluent increased significantly ($p < 0.05$). The levels of pH, potassium (ppm), sulphur (ppm), and sodium (ppm) increased in effluent, but not significantly. In September, aquaponic effluent had significantly lower levels of EC (369 ± 9.50 µS cm^{-1}), Total-N (ppm), P (ppm), K (ppm), and S (ppm) compared to influent (Table 2). The level of CO_3 (72 ± 4.78 ppm) increased significantly. The pH level increased, and the HCO_3 level decreased in the effluent, but this was not significant.

TABLE 1 Physical water parameters of the aquaponics system observed on different dates.

Day	Date	pH	Temperature (°C)	DO (mg/L)
1	5-Jun-23	7.75 ± 0.041	29.32 ± 0.024	4.83 ± 0.047
2	20-Jun-23	7.63 ± 0.236	29.47 ± 0.047	3.85 ± 0.039
3	5-Jul-23	7.70 ± 0.082	27.67 ± 0.094	4.73 ± 0.047
4	20-Jul-23	7.57 ± 0.047	28.65 ± 0.041	3.62 ± 0.021
5	5-Aug-23	8.43 ± 0.047	27.93 ± 0.047	4.14 ± 0.043
6	20-Aug-23	7.73 ± 0.047	28.14 ± 0.033	3.95 ± 0.041
7	5-Sep-23	7.80 ± 0.141	29.63 ± 0.094	4.35 ± 0.037
Mean ± SD		7.8 ± 0.267	28.69 ± 0.737	4.21 ± 0.418
Range		7.57 – 8.43	27.67 – 29.63	3.62 – 4.83

TABLE 2 Water quality tests results in the aquaponics influent and effluent in different months.

Parameter	July			September		
	Influent	Effluent	Sig.	Influent	Effluent	Sig.
pH	9.60 ±1.25	9.75 ± 1.39	ns	6.17 ± 1.10	6.92 ± 1.11	ns
EC (µS/cm)	394 ±13.00	338 ± 11.00	**	598 ± 17.50	369 ± 9.50	***
CO_3 (ppm)	72 ± 6.90	18 ± 4.31	***	12 ± 1.630	72 ± 4.78	***
HCO_3 (ppm)	189.10 ± 9.31	237.90 ± 7.21	**	219.6 ± 8.10	213.5 ± 7.50	ns
Total-N (ppm)	4.20 ± 0.99	7.00 ± 0.7	*	11.2 ± 1.02	5.6 ± 0.70	**
P (ppm)	0.83 ± 0.11	0.50 ± 0.11	*	1.69 ± 0.07	0.15 ± 0.01	***
K (ppm)	15.13 ± 1.29	16.54 ± 1.7	ns	14.5 ± 1.18	2.618 ± 1.10	***
S (ppm)	3.51 ± 0.27	3.54 ± 0.21	ns	8.96 ± 1.18	1.48 ± 0.18	**
Na (ppm)	43.99 ± 4.99	46.84 ± 4.11	ns	0	0	--

EC = Electric conductivity; P = Phosphorus, K = Potassium; S = Sulphur, Na = Sodium
Values are expressed as mean ± standard deviation.
*** = denotes 0.01% level of significance; ** = 1% level of significance; * = 5% level of significance; ns = Not significant

TABLE 3 Water quality parameters observed in hydroponics influent and effluent in different months.

Parameter	July			September		
	Influent	Effluent	Sig.	Influent	Effluent	Sig.
pH	9.7 ± 1.10	10.4 ± 1.10	ns	6.8 ± 1.52	6.87 ± 1.5	ns
EC (µS/cm)	598 ± 10.00	391 ± 12.00	*	329 ± 13.00	357 ± 13.50	ns
CO_3 (ppm)	72 ± 9.00	42 ± 6.00	*	0.00	0.00	--
HCO_3 (ppm)	67.10 ± 8.00	97.6 ± 10.31	*	213.5 ± 11.00	231.8 ± 6.10	ns
Total-N (ppm)	1.40 ± 1.02	5.60 ± 1.00	**	5.6 ± 3.23	5.60 ± 2.02	ns
P (ppm)	1.32 ± 0.09	0.79 ± 0.06	**	1.016 ± 0.01	0.81 ± 0.06	*
K (ppm)	4.84 ± 1.12	4.84 ± 1.17	ns	5.24 ± 1.27	5.24 ± 1.68	ns
S (ppm)	3.31 ± 0.09	3.84 ± 0.9	ns	2.9 ± 0.21	2.25 ± 0.21	*
Na (ppm)	23.62 ± 5.32	24.43 ± 4.00	ns	0	0	--

EC = Electric conductivity; P = Phosphorus, K = Potassium; S = Sulphur, Na = Sodium
Values are expressed as mean ± standard deviation;
*** = denotes 0.01% level of significance; ** = 1% level of significance; * = 5% level of significance; ns = Not significant

In hydroponics, HCO_3 (97.6 ± 10.31 ppm), and Total-N (5.60 ± 1.00 ppm) significantly increased in the effluent than the influent during July. The levels of EC (391 ± 12.00 µS cm^{-1}), CO_3 (42 ± 6.00 ppm), and P (0.79 ± 0.06 ppm) significantly decreased in effluent. pH, potassium, sulphur, and sodium levels differed insignificantly (Table 3). In September, only the phosphorus and sulphur levels decreased significantly in September (Table 3). The levels of pH, EC (µS cm^{-1}), the HCO_3 increased in effluent but not significantly. The levels of Total-N (ppm) and K (ppm) did not change.

3.3 Effects of types of system (aquaponics vs. hydroponics) on the physicochemical parameters of water from effluent and influent

The physicochemical parameters of influent and effluent are indicators of nutrient intake by plants in both aquaponic and hydroponic systems (Mishra *et al*. 2024). In the present study, some of these parameters of influent and effluent between the two culture systems differed in July and September.

In July, levels of HCO_3, K, and Na were higher in both of influent and effluent of aquaponics than hydroponics, while EC was lower in aquaponics, showing a significant difference ($p < 0.05$). The levels of pH, total-N, and S differed insignificantly in both effluent and influent. CO_3 levels were significantly lower in aquaponics effluent than in hydroponics, but not in influent.

In September, CO_3, P, and S exhibited a significant increase in both influent and effluent of aquaponics than hydroponics. EC, K levels also showed a significant increase in aquaponics influent, while changes in effluent were not statistically significant. In general, the physicochemical parameters of both aquaponics and hydroponics effluent changed after the cycle was completed and fed into the influent (Table 3).

3.4 Fish growth performance

The length and weight of the experimental fish increased significantly during the study period. Figure 2 and Table 4 show the growth performance of experimental fishes. Regression analysis revealed that the growth of fish in terms of total length and body weight was consistent (Figure 2). The growth parameters of fish in terms of length gain (cm), weight gain (g), percent weight gain, daily growth rate, specific growth rate (SGR), food conversion ratio (FCR), survival rate, and production of fish (kg/m^3/90 days) are presented in Table 4.

3.5 Leaf analysis

The study found that the highest nitrogen, potassium, and sulphur content (5.54%, 3.10% and 0.61%) in leaves was found in aquaponics, while the phosphorus (0.85%) was higher in hydroponics (Table 5).

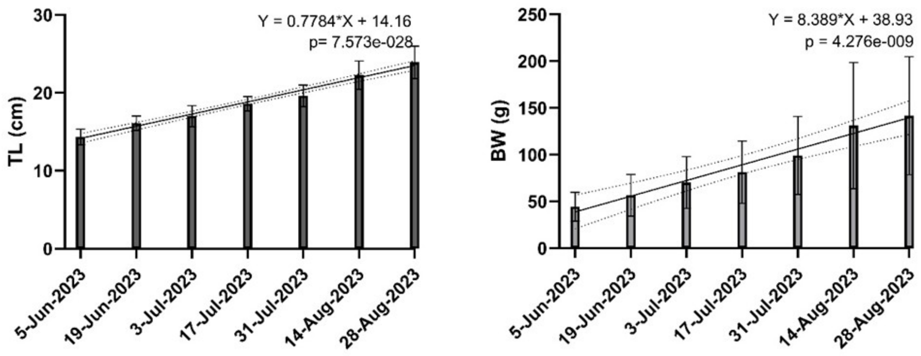

FIGURE 2 Total length (TL) and body weight (BW) of tilapia sampled from aquaponics fish tanks during the study period.

TABLE 4 The growth performances of fish in terms of length gain (cm), weight gain (g), percent weight gain, daily growth rate, specific growth rate (SGR), food conversion ratio (FCR), survival rate and production of fish (kg/m^3/90 days).

Growth parameters	Mean ± SD
Mean initial length (cm)	14.41 ± 0.66
Mean final length (cm)	24.95 ± 1.47
Length gain (cm)	10.54 ± 1.51
Mean initial weight (g)	49.81 ± 4.29
Mean final weight (g)	162.52 ± 23.03
Weight gain (g)	112.71 ± 21.75
% weight gain	227.23 ± 42.98
Daily growth rate (g)	1.34 ± 0.26
Specific Growth Rate (%/day)	1.4 ± 0.16
Food Conversion Ratio (FCR)	1.85 ± 0.37
CF	1.04 ± 0.06
Survival rate (%)	96.67
Production (kg/tank (750 L)/90 days)	7.47
Production kg/m^3/90days	9.96

TABLE 5 Table showing the nutrient percent in leaves of Indian spinach from aquaponics and hydroponics culture systems.

Nutrients	Aquaponics	Hydroponics	Sig.
Nitrogen (%)	5.54 ± 0.95	3.42 ± 0.49	*
Phosphorus (%)	0.78 ± 0.16	0.85 ± 0.26	ns
Potassium (%)	3.10 ± 0.25	2.49 ± 0.42	ns
Sulphur (%)	0.61 ± 0.21	0.05 ± 0.01	*

Values are expressed as mean ± standard deviation; *** = denotes 0.01% level of significance; ** = 1% level of significance; * = 5% level of significance; ns = Not significant

3.6 Plant growth and yield

The study found plant heights and leaf counts varied between two culture systems. In all sampling, Indian spinach produced in the aquaponics system showed higher levels of plant height, number of leaves and leaf area. Plant height was significantly higher ($p < 0.05$) in aquaponics compared to hydroponics during the second, fifth, and sixth samplings (02-Jul-2023, 17-Aug-23, and 02-Sep-23) (Figure 3A). The number of leaves was significantly higher in aquaponics during the second, fourth and fifth sampling (02-Jul-23, 02-Aug-23 and 17-Aug-23) (Figure 3B). Though the number of leaves was higher in all the samples, only the fifth sampling on 17-Aug-2023 was significantly higher in aquaponics than hydroponics (Figure 3C).

The present study also observed higher plant weight in aquaponics than in hydroponics. The highest weight (82.05 ± 23.31 g) was found in aquaponics, at the same time 48.97 ± 25.32 g was found in hydroponics on 2nd September 2023. The lowest weight (22.25 ± 8.56 g) was found in hydroponics on 2nd July 2023 (Figure 4A).

The total yield of Indian spinach was higher in aquaponics than in hydroponics. The total surface area of the beds was 0.462 m^2 (3 × 0.154 m^2). The production of Indian spinach was 1.33 kg (2.88 kg m^{-2}) in aquaponics and 0.70 kg (1.52 kg m^{-2}) in hydroponics, respectively (Figure 4B).

4 | DISCUSSION

4.1 Water quality parameters of the fish tank

The present study found the water quality levels of the fish tank within optimum values reported by different studies. The pH of fish tank water ranged from 7.57 to 8.43, with the highest value recorded on August 5th at 8.43, and the lowest on July 20th at 7.57. DeLong *et al.* (2009) stated that tilapia can survive in a wide range of pH from 5 to 10, but the optimum pH for tilapia growth is 6 to 9. The average temperature of fish tank water was 28.69 ± 0.74°C, where the range was 27.67 to 29.63°C, which was within the acceptable range for tilapia (El-

Sayed and Kawanna 2008; Nehemia and Maganira 2012; Henson *et al*. 2018). Water temperature is crucial for tilapia's growth, with the lethal temperature being 10°C (Henson *et al*. 2018; Nivelle *et al*. 2019). Optimal temperature ranges from 27 to 29°C, with good growth rates reported at 25 to 32°C (DeLong *et al*. 2009; Henson *et al*. 2018). Dissolved oxygen level ranged from 3.62 ppm to 4.83 ppm with an average level of 4.21 ± 0.42 ppm. Tilapia is hardy and can survive in a wide range of dissolved oxygen (DO) levels, with good growth observed at 5.0 mg L^{-1} (Abdel-Tawwab *et al*. 2014). The DO level was also within the acceptable range.

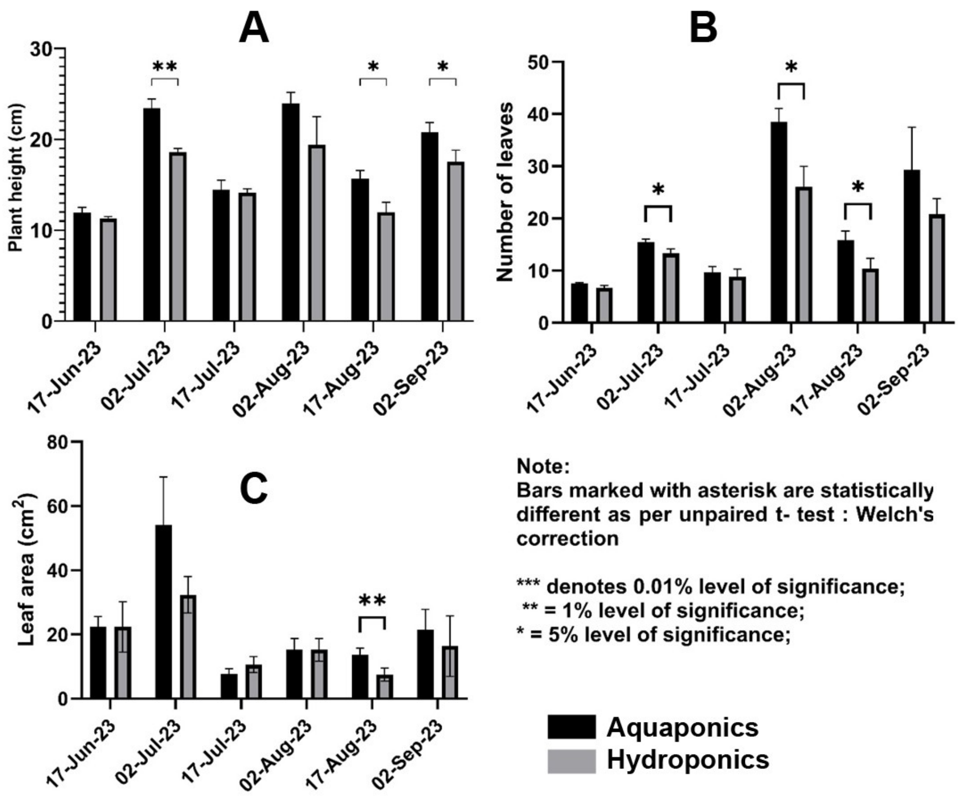

FIGURE 3 A: Plant height of Indian spinach produced in aquaponic and hydroponic systems; B: Number of leaves of Indian spinach produced in aquaponic and hydroponic systems; C: Leaf area of Indian spinach produced in aquaponic and hydroponic systems.

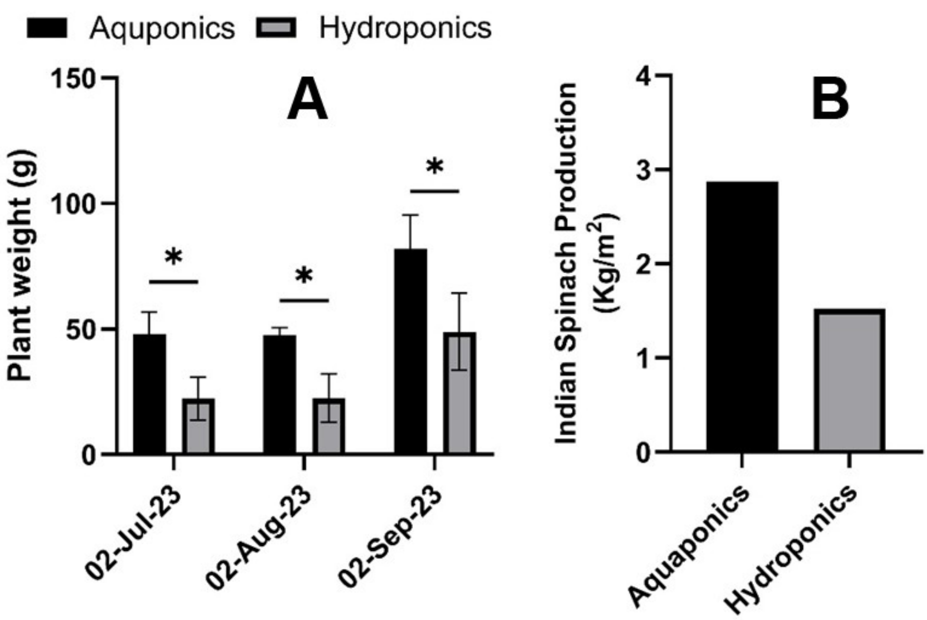

FIGURE 4 A: Monthly average plant weight (g); B: Indian spinach production in aquaponics and hydroponics.

4.2 Physicochemical parameters of influent and effluent in aquaponics and hydroponics systems

Water quality lab test results were found suitable for EC, CO_3, HCO_3, total-N, phosphorus, potassium, sulphur, and sodium in the present aquaponics and hydroponics study. According to Stone and Thomforde (2004), the EC range is

100 –2,000 µS cm^{-1}, whereas the acceptable range of EC is 30 – 5,000 µS cm^{-1} for pond fish culture. In this study, the highest EC value (598 ± 17.50 µS cm^{-1}) was found in aquaponics influent and the lowest (338.00 ± 11.00 µS cm^{-1}) in aquaponics effluent, indicating plant utilization of nutrients. Electricity conductivity (EC) is the capacity of dissolved solids to pass electricity in water, indicating the concentration of electrolytic substances (Walton 1989). Stone and Thomforde (2004) also mentioned the optimum range of total NH_3-N for fish is 0–2 mg L^{-1} and unionized NH_3-N is 0 mgL^{-1}. According to Hong-xin *et al*. (2001), hydroponic vegetables may purify up to 57.46, 51.72, 3.7, and 10.67% of their ammonia-N, nitrite-N, nitrate-N, and total-N, respectively. The total-N range in the current study was 1.40 ± 1.02 to 5.6 ± 3.23 mg L^{-1} in the hydroponics system and 4.20 ± 0.99 to 11.2 ± 1.02 mg L^{-1} in the aquaponics system. Boyd (1998) mentioned that for pond culture, an acceptable range of concentrations of CO_3, HCO_3, phosphorus, sodium, potassium and sulphur is 0 – 20, 50 – 300, 0.005 – 0.2, 2 – 100, 1 – 10 and 5 – 100 mg L^{-1} respectively. The study found that the concentrations of HCO_3, phosphorus, sodium, potassium, and sulphur were within the acceptable range, except for CO_3.

4.3 Effects of types of systems on the water quality parameters

The difference in electrical conductivity (EC) between effluents and influents was significantly greater in the aquaponics system compared to the hydroponics system. Specifically, the EC levels decreased in the aquaponics effluents, whereas they increased in the hydroponics effluents in July and September. Electrical conductivity represents the number of electrolytes in solution. The decrease of EC in effluents may be due to the uptake of plants and, removal of ions. Biofilter converts ammonia into nitrate, but this doesn’t increase enough to offset the plant uptake. In the aquaponics system, the elevated ions in influents may come from the fish feed. Different commercial fish feed contains ions such as Ca, Mg, K, PO_4^{3-}, SO_4^{2-}, and trace metals (Mannzhi *et al*. 2021). The nitrification process continuously produces the ion which may enter the system. Biogas slurry often has suspended solids that are removed through settling, dilution, and filtration before including them in the system. Aquaponics mineralizes solids on-site, making ions available and raising EC more effectively which may raise the ion compounds into the aquaponics system. Even if fish waste starts with a lower concentration, the system biology and water recycling make aquaponics EC rise above hydroponics (Lama *et al*. 2025).

The decline of CO_3^{2-} concentrations in July in both aquaponic and hydroponic effluents suggests increased acidification of the systems, likely associated with microbial nitrification, which consumes alkalinity and releases hydrogen ions (H^+) (Rakocy *et al*. 2006). The subsequent increase of CO_3^{2-} in the aquaponic effluent during September may be attributed to reduced nitrification efficiency at higher temperatures or lower organic loading rates later in the season (Wongkiew *et al*. 2017).

Bicarbonate (HCO_3^-) increased in both effluents during July, consistent with shifts in carbonate buffering during periods of high CO_2 production from respiration and microbial mineralization. The significantly greater increase in aquaponics compared with hydroponics aligns with the higher organic input from fish metabolism, which enhances carbon cycling (Endut *et al*. 2014). In contrast, HCO_3^- decreased in aquaponics and increased in hydroponics in September, highlighting the dynamic relationship between mineralization rates and plant uptake in the two systems.

Total nitrogen levels increased from influent to effluent in both systems during July, with hydroponics showing a significantly greater increase. This pattern indicates that mineralization of organic nitrogen—enhanced by biofilter activity—surpassed plant uptake during this period (Hu *et al*. 2015). The subsequent decline of total-N in aquaponics in September suggests improved assimilation by plants or reduced nitrogen loading from fish waste, while hydroponics remained unchanged. As established in aquaponic systems, nitrifying bacteria efficiently convert organic and ammoniacal nitrogen into nitrate, increasing the circulating inorganic N despite continuous plant absorption (Goddek *et al*. 2015).

Phosphorus (P) concentrations decreased in the effluents of both systems during July and September. The lack of significance in July but significant reduction in aquaponics during September indicates higher P uptake or retention within aquaponic components such as microbial biofilms, fish solids, and sedimented particulates (Eck *et al*. 2019). Meanwhile, the increase in influent P suggests limited P absorption by Indian spinach, consistent with the relatively low P requirement of many leafy vegetables (Resh 2022).

Overall, the comparative nutrient dynamics highlight fundamental biochemical differences between aquaponic and hydroponic systems. Organic nutrient mineralization, microbial transformations, and fish-driven inputs shape aquaponic effluent composition, whereas hydroponic nutrient profiles remain more stable due to controlled supplementation. These findings align with established literature demonstrating that aquaponic systems exhibit more complex and fluctuating nutrient patterns than hydroponics (Goddek *et al*. 2015; Delaide *et al*. 2016).

4.4 Fish growth parameters

In the current study, the initial length and weight of stocked tilapia were 15.02 ± 1.19 cm and 52.09 ± 2.1 g, respectively, with 80 individuals m^{-3} stocking density. In aquaponics, Akter *et al*. (2018) used a similar stocking density for water spinach and tilapia. Hossain *et al*. (2022)

and Salam *et al*. (2014) stocked a higher number of fingerlings (150 and 1 individual m^{-3}, respectively) as they stocked smaller fingerlings. Despite different studies reporting higher stocking densities, considering the larger size of the fry, our stocking density was lower. Also, we had planted only 4 plants per bed, which was lower than the planting density of Hossain *et al*. (2022). Higher stocking density increased the production of leafy vegetables (Rahmatullah *et al*. 2010; Abdelrahman 2018). On the other hand, higher stocking density also deteriorates water quality if the plant can't intake a significant portion of the nutrient (Ani *et al*. 2022).

The present study found the length gain of experimental fish was 10.54 ± 1.51 cm, weight gain 112.71 ± 21.75 g, with a percent weight gain of 227.23 ± 42.98, specific growth rate of 1.4 ± 0.16 % day^{-1}. The tilapia culture was conducted for 90 days, with a food conversion ratio of 1.85 ± 0.37. The survival rate was 96%, and the total fish production was recorded at 7.47 kg/tank/90 days. These findings are slightly higher than Hossain *et al*. (2022) as they stocked comparatively smaller fingerlings and cultured for 70 days instead of 90 days.

4.5 Leaf analysis

The higher nitrogen content revealed that the aquaponic system provided more nitrogen content than hydroponics (Yang and Kim 2020). Likely, the sulfur content was higher in leaves from the aquaponics system. Biogas slurry is a partial nutrient medium for hydroponics compared to feces and unused feed particles in tilapia – aquaponics (Wang *et al*. 2019). In a hydroponics system, nutrients are more prone to waste than in a biofilter system in aquaponics (Yang and Kim 2020).

4.6 Plant growth and yield

In the present study, significantly higher height of Indian spinach plants was found in aquaponics (18.37 cm) than that of hydroponics (15.47 cm). Similar to the current experiment, Hossain *et al*. (2014) found that the plant height ranged between 9.42 to 13.92 cm and 17.83 to 29.33 cm among the biogas slurry treatments at 30 and 60 days after sowing. The average number of Indian spinach leaves in hydroponics (12.07) was lower than in aquaponics (15.52). The mean weight of Indian spinach in aquaponics and hydroponics systems was found to be 59.25 g and 31.23 g in this experiment which is more or less similar to the findings from Roy *et al*. (2013).

The total yield of Indian spinach was higher in aquaponics than in hydroponics. The production of Indian spinach was 1.33 kg (2.88 kg m^{-2}) in aquaponics and 0.70 kg (1.52 kg m^{-2}) in hydroponics, respectively. Aquaponics production was higher than Hossain *et al*. (2022). Hydroponic production was also higher in the present study than in Akter *et al*. (2021).

5 | CONCLUSIONS

The study evaluated the production of Indian spinach in aquaponics and hydroponics systems, using fish wastewater and biogas slurry solution which was conducted at Bangladesh Agricultural University, Mymensingh. The water quality parameters were suitable for tilapia, and the concentration of nutrients was higher in aquaponics. There was a difference in nutrient loads and their absorbance between the hydroponics and aquaponics systems. The study found that aquaponics produced higher plant height, leaf area, and root weight than hydroponics. The highest N, K, and S content in leaves was found in aquaponics, while the P content was higher in hydroponics. This study only covered up only 97 days of investigation, so a further investigation is required to reach a final recommendation as well as conclusion. It is suggested that large-scale experimentation for taking it as policy-making tools and guidelines to promote food security and malnutrition reduction.

CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHORS' CONTRIBUTION

Bably Akter: Conceptualization, Data Curation, Methodology, Software, Visualization, Writing- Original draft preparation, Farjana Akhter: Data Curation, Methodology, Software, Writing – Reviewing and Editing, Shaharior Hashem: Data Curation, Formal analysis, Software, Validation, Writing – Reviewing and Editing, Md. Hamidur Rahman: Writing – Reviewing and Editing, Homayora Yeasmin: Data Curation, Writing – Reviewing and Editing, S. M. Rayhan: Data Curation, Writing – Reviewing and Editing.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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