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Potentials of Integrating Fish Culture with Floating Bed Vegetable Production in Closed Pond System

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ABSTRACT

The age-old floating bed or aggregated hydroponic vegetable production system in flood prone areas in Bangladesh has been gaining interest in research and development programme. With the goal of efficient utilization of available land and water resources in rural areas, an experiment was conducted to assess the possibility of integrating hydroponic vegetable production with pond fish culture system. Nine ponds of 130m^2 each were prepared and out of those, each of six ponds was set with one floating vegetable bed of 6.75 m^2 (4.5 m × 1.5 m) that was prepared using mainly water hyacinth. The experiment was designed with three treatments of (i) fish plus floating vegetable bed plus feed (T1), (ii) fish plus floating vegetable bed (T2), and (iii) fish plus feed (T3) with three replications for each. Two fish species GIFT (*Oreochromis niloticus*) and silver barb (*Barbados gonionotus*) with 1:1 ratio were cultured at a stocking density of 3/m^2. Vegetables viz., okra, swamp cabbage, Indian spinach and water taro were grown in floating beds. While physicochemical water quality parameters (temperature, dissolved oxygen, pH and ammonia) were found similar ($P > 0.05$) among the treatments, abundance in plankton varied significantly ($P < 0.05$). Both species in T1 and T2 showed strong selectivity on detritus and insect remains, with the Ivelv's electivity values of 8.5-9.8, sourcing from the vegetable beds, The significantly highest ($P < 0.05$) specific growth rate (GIFT, 1.56 ± 0.02%/ day; silver barb, 1.89 ± 0.05%/day) and production (GIFT, 11.46 ± 0.65 kg/decimal; silver barb, 10.25 ± 0.53 kg/decimal) were recorded from T1. In addition to fish, about 36.76 kg yield of vegetables obtained from the hydroponic system in T1 that resulted in 4.9-times higher net income benefit, compared to fish ponds without a hydroponic system. The overall results indicate the potential for adopting aggregated hydroponic system with fish culture in rural ponds for sensitive benefits relating to household resource utilization, nutrition and income.

Introduction

The development of a profitable, sustainable and environment-friendly agricultural system faces a number of multidimensional challenges for ensuring food security of the vast population in Bangladesh. One of the most important challenges is not only the country's agricultural land is declining over the years, but a huge area in some parts of the country remained flooded for a prolonged period of almost every year, causing a severe impact on agricultural production and upon the lives of the farming population as well (Rana 2014). The country has to minimize these challenges to produce more food from available land as well as aquatic resources by practicing appropriate farming system.

Three development pathways for farming systems can be distinguished, namely: (i) extensification, i.e., extending the cultivated area while maintaining or reducing input levels per unit area; (ii) intensification, i.e., increasing production per unit area through more intensive production practices in land use and technology; and (iii) diversification, i.e., changing farm practices and products to align them better with social, environmental and economic contexts (Erenstein 2006). One form of diversified agriculture is Integrated Agriculture-Aquaculture (IAA) system, which has been defined as "concurrent or sequential linkages between agriculture and aquaculture, directly on-site, or indirectly through off-site needs and opportunities, or both" (Prein 2002). This system is practiced in

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Bangladesh, China, India, Indonesia, Malaysia, Thailand and Vietnam in different forms of integrating aquaculture with rice and/or pond dyke vegetable cultivation (Edwards *et al.*, 1988).

While there is an urge of combining the disciplines of ecology and engineering to address the environmental as well as land problems in cost effective way (Kangas 2004), there are examples of ecological engineering as "hydroponics" (growing plants instead of soils) and "aquaponics" (which combines aquaculture with hydroponics) under controlled and symbiotic environmental conditions. The most common hydroponics technology is mainly of two types: (i) "liquid hydroponic system", where the plant roots are directly exposed to the nutrient solution without any other growing medium and the solution is reused; (ii) "aggregate hydroponic" system, where a solid, inert medium provides support and nutrient for the plants (Resh, 2001). Aquaponics technology is so far run mainly within a greenhouse recirculating systems and is not often applicable to local aquaculture systems. Furthermore, while the area for aquaponics can be used for several income generating or cost reducing functions, then investment for the greenhouse-structure and housed system components needs to be minimized per unit output (Zweig, 1986). Integration of fish culture with hydroponics in closed pond system may well fit these criteria. Aquaponics in fish pond placing pored plastic bottles, containing coconut husk and breaklets as plant growing media, on bamboo made raft has been suggested to be promising in vegetable production and water quality improvement (Salam *et al.*, 2013), but this system had positive effects neither on fish growth nor on natural fish food production. An alternative strategy needs to develop that allows fish culture pond to support increased fish production and vegetable production concurrently.

There is an age-old agriculture practice in flood prone areas of Bangladesh, where seasonal vegetables are grown on the water in a "floating bed" made of water-hyacinth, algae and other plant residues (Islam and Atkins 2007; Irfanullah *et al.*, 2007), which can be termed as "aggregated hydroponic" system (Resh, 2001). Using the principle of aquaponics, there is a possibility to develop a bio-integrated system linking the floating bed or aggregated hydroponics with the pond aquaculture system. The basic strategy behind the concept would be to maximize the utilization of available resources and the functions of each system's biological components to improve economic performance. However, research based information are lacking on the productivity dynamics in integrated floating bed agriculture and aquaculture in pond environment and their effects on the growth and production of fish and vegetable as well. With this background, the present research was designed to assess the hypothesis that integration of indigenous floating bed vegetable growing system with fish culture in pond will perform better for per unit farm output on test than fish ponds without floating bed vegetable system.

Materials and Methods

Design of the Experiments

The experiment was conducted in nine earthen ponds, having the water area of 130 m^2 each, for a period of 201 days from March to September 2014. As has been shown in Table 1, three different treatments were assigned in a Completely Randomized Design (CRD).

Table 1. Design of the experiment showing treatments with variables, replications and fish stocking

Treatment		Replications	Fish stocking		
Variables			Species	Ratio	Density (m^2)
T1	FVB + Fish + Feed	3	GIFT and SB	1:1	3
T2	FVB + Fish	3	GIFT and SB	1:1	3
T3	Fish + Feed	3	GIFT and SB	1:1	3

FVB = Floating vegetable bed; GIFT: Genetically Improved Farmed Tilapia (*Oreochromis niloticus*); SB: Silver barb (*Barbodes gonionotus*).

Pond Preparation

Ponds were completely sun dried, all vegetation were removed and treated with lime (CaO) at the rate of 1 kg/decimal one week prior to water supply. After three days of liming, each pond was filled-in up to 30 cm with underground water. Urea and TSP (Triple Super Phosphate) were applied, at the rate of 100 g and 75 g per decimal respectively, to trigger natural food production. The ponds were left for three days and then water was supplied gradually to a depth of 1.5 m.

Preparation of Floating Bed

For each of the floating beds, a bamboo frame of 4.50 m in length, 1.5 m in width, and about 80 cm in height was made and placed in the pond, following the assignment of respective treatment (Table 1). The floating beds were prepared following techniques described elsewhere (Irfanullah *et al.*, 2007). Water hyacinth were collected from the nearby canals and beels and dumped into a bamboo frame to make an initial layer of about 30 cm. The 1^{st} layer was pressed manually and left for seven days for well settling. The 2^{nd} layer was then made using water hyacinth with the same height like the previous one. After 3-4 days of setting the 2^{nd} layer, a mixture of semi-decomposed water hyacinth and duckweeds was given on it at a height of about 12 cm. This way the final settling was done, leaving no empty space on the bed top and in the bamboo frame. The beds were kept floated in the water so that the top of the bed remained at least 15-10 cm above the water level.

Seeding of Vegetable Crop

Seeds of different vegetables *viz*., ladies finger, swamp cabbage, Indian spinach and water taro were sowed in a proportionate quantity on the top of each of the floating vegetable bed. About 5-7 days prior to sowing of the seed, a mixture of TSP (80 kg/ha), MP (50 kg/ha) and previously made compost of water hyacinth was applied on the bed. Once the seeds germinated and started to grow, urea (100 kg/ha) was applied as top dress depending on the growth of vegetables.

Fish Stocking and Feeding

A 1:1 combination of GIFT (Genetically Improved Tilapia), and Silver barb, fry was stocked in each of nine experimental units at the density of 3/m^2 (120/decimal). The fish fry were collected from a commercial hatchery, transported using oxygenated bag, and acclimatized with the pond water prior to stocking. At stocking, fish fry ($n \approx 25$) were randomly measured for initial individual length (cm) and weight (g).

Fish were fed with a commercial floating feed (Saudi Bangla Fish Feed) (30% crude protein) twice a day (at 10:00 and 16:00) at the rate of 5% of body weight for the 1st month and reduced to 3% thereafter. Daily feeding rate was calculated adjusting the fish body weight fortnightly. Neither any inorganic nor organic fertilizer was used in the experiment.

Water Quality Parameters

Temperature (°C), Dissolved oxygen (mg/L), pH, and Ammonia (mg/L) were measured fortnightly using a portable digital Celsius thermometer, DO meter (Model: Lutron, PDO-519), pH meter (Model: sensION PH3 Meter Lab PHM310) and spectrophotometer (Model: DR-2010 HACHKit), respectively. For the qualitative and quantitative study of phytoplankton and zooplankton, ten litres of water samples were collected fortnightly from five different locations of each pond and passed through a plankton net (mesh size of 55 micron meter) and finally concentrated into 100 mL. Then concentrated samples were preserved in small plastic bottles with 5% buffered formalin for further study. Periphyton samples from the bamboo frames and harder solid parts of the floating vegetable beds were taken by scraping with the help of razor blades. Scrapings were kept in 100 mL water and vigorous shaking was done. Then the samples were preserved in 5% formalin for future study. Both plankton and periphyton were identified, up to genus level following the guidelines of APHA (2005) and Bellinger (1992), and counted under a microscope using Sedgewick-Rafter counting Cell S (S-R cell). The abundance of plankton and periphyton was estimated following the formula of Clesceri (1989) and Rahman (1992) (Eq. 1):

$$N = \frac{(A \times 1000 \times C)}{V \times F \times L} \quad (1)$$

where N = number of plankton cells per litre of the original water, A = total number of plankton counted, C = volume of final concentrate of samples in ml, V = volume of a field in cubic mm, F = number of the fields counted and L = volume of original water in litre.

Fish Growth and Production Performance

At each fortnight sampling, at least 25 fish of both species were sampled randomly for recording individual length (cm), and weight (g), using a measuring scale and a battery-operated digital balance, respectively. At harvest, 50 fish of both species were measured for individual length (cm) and weight (g), using a measuring scale and digital top loading balance (TITAN 5 kg × 1 g). All harvested fish from each experimental unit were counted for estimating survival rate and were weighed for estimating the total production. The weight data were used to calculate individual daily weight gain and specific growth rate (SGR). Fish weight and feed data were used to determine feed conversion ratio (FCR). The following formulae were used to calculate the above parameters:

$$\text{Weight gain (g)} = \text{Mean final weight } (W_2) - \text{Mean initial weight } (W_1) \quad (2)$$

$$\text{Average daily weight gain (g/day)} = \frac{\text{Weight gain (in g)}}{\text{Culture period (days)}} \quad (3)$$

$$\text{Specific growth rate (\%/day)} = \frac{\ln W_2 - \ln W_1}{T_2 - T_1} \times 100 \quad (4)$$

where W_2 = Final body weight at T_2 -means harvesting time, W_1 = Initial body weight at T_1 -means stocking time.

$$\text{FCR} = \frac{\text{Total Feed fed (in g)}}{\text{Total wet weight gain (in g)}} \quad (5)$$

Gut Content Analysis

Ten GIFT and ten silver barb were sampled randomly from each pond prior to the day of final harvest for gut content analysis. The stomach content was collected from live fish and analysis was carried out in the laboratory. A longitudinal cut was made along the stomach and the contents were transferred into a Petri dish. Then the stomach contents were preserved in 5% neutralized formalin for further analysis. Individual gut contents were then kept for five minutes to remove excess formalin. A 1ml sub-sample was transferred to a counting chamber and all algal particles in ten squares chosen randomly were identified and counted under a compound binocular microscope (HumaScope). The data collected were used to calculate Ivlev's index (E) according to Strauss (1979) using the formula (Eq. 6):

$$\text{Electivity index (E)} = \frac{(ri - pi)}{(ri + pi)} \quad (6)$$

where, ri = proportion of i food item in fish stomach, pi = proportion of i food item in the water sample. E values of -1 and +1 indicate complete avoidance and exclusive feeding, respectively.

Vegetable Harvesting

Vegetables from the floating bed were harvested when matured. Leafy vegetables like swamp cabbage (Kolmi Shak) and Indian spinach (Pui Shak) were harvested repeatedly. Fruity vegetables like okra and taro were harvested after getting matured. All of the vegetables were harvested at different times throughout the whole experimental period.

Data Analysis

Data of fish growth gain and production, feed utilization efficiency, and water quality variables obtained from the experiment were subjected to one-way Analysis of Variance (ANOVA) using SPSS (version 17) and Statistix 10. Duncan's Multiple Range Test (DMRT) was applied for significance at 5% level. Net benefit from the production of fish and vegetables was estimated simply by calculating input costs and price of the produce.

Results and Discussion

The mean values of dissolved oxygen (DO) and ammonia varied significantly ($P < 0.05$), while that of temperature and pH were similar ($P > 0.05$) among the treatments (Table 2). Though DO and ammonia values were significantly higher and lower, respectively, in the ponds having floating vegetable bed (FVB), but were within the optimal levels for the growth of culture fish. According to Riche and Garling (2003), the preferred DO level is above 5 mg/L, but a concentration of 3 mg/L should be in the lower limit for optimum growth of tilapia. Bhatnagar *et al.* (2004) also suggested that DO levels of 1–3 ppm have sub lethal effect on growth and feed utilization, while that of 0.3–0.8 ppm are lethal to fish. In the current study, ponds under T2 and T3 recorded DO levels of more than 3 mg/L, but that under T1 and T2 recorded less than 3 mg/L at around 80 days with an increasing trend thereafter. The significantly higher DO levels of more than 5 mg/L in ponds without FVB (T3) suggest that the progressive significant decrease in DO, with as low as 1.6 in T1 and 2.6 in T2 on day 80, could have been as a result of increased uptake by microorganisms during the decomposition of vegetable bed materials in pond.

Table 2 shows that the mean ammonia levels in ponds with FVB (T1 and T2) were significantly higher than in ponds without FVB (T1) and much higher than the recommended range of 0.05-0.1 mg/L for aquaculture pond waters (Boyd and Tucker 1998). While the maximum limit of ammonia concentration for aquatic organisms is 0.1 mg/L (Santhosh and Singh 2007), ammonia levels of < 0.2 mg/L has been recommended suitable for pond fishery (Bhatnagar and Singh 2010) Mean ammonia levels of 0.01–0.4 mg/L (Makori *et al.*, 2017) and 0.23 ± 0.07-0.26 ± 0.08 mg/L (Mbonde, *et al.*, 2017) also have been reported in tilapia culture ponds without any adverse effects on growth and survival. In the current study, the increase in ammonia levels to as high as 0.3 mg/L at 120 days in ponds of T1 might be associated with the combined decomposition of vegetable bed materials and uneaten feed. This increase in ammonia, however, did not affect the fish growth, as ammonia decreased thereafter with the commencement of monsoon rainfall.

There was significant differences in mean length and weight gain and SGR of both GIFT and silver barb among the treatments (Table 3). GIFT obtained from the T1 (FVB + Fish + Feed) pond registered the highest ($P < 0.05$) mean weight (244.00 ± 10.39 g) while that in T2 (FVB + Fish) recorded the lowest mean weight (114.27 ± 24.20 g) but similar ($P > 0.05$) with the mean weight of 141.25 ± 16.37 g in T3 ((Fish + Feed). In contrast, Silver barb obtained from the T1 (FVB + Fish + Feed) pond registered the significantly highest ($P < 0.05$) mean weight (243.22 ± 8.19 g) while that in T2 (FVB + Fish) recorded the lowest ($P < 0.05$) mean weight (124.38 ± 7.74 g) among the treatments (Table 3). The results of the current study is consistent with the findings of Wahab *et al.* (2019) who reported mean harvesting weight of Tilapia ranging from 136.97 ± 10.63 to 258.59 ± 18.76 g in farmers ponds over a 180-day culture period. Nevertheless, the highest weight gain of tilapia (233.40 ± 5.79 g) obtained in the present study was higher than that has been reported by Shahin *et al.* (2011); Sarker *et al.* (2014); Ali *et al.* (2016). In case of Silver barb, the weight gain (237.82 ± 4.45 g) was higher than 144.5 ± 3.19 g that has been reported by Shah *et al.* (2008) in a 180-day pond mixed of GIFT and Silver barb. Shah *et al.* (2008) also reported that GIFT showed a reduced growth in GIFT when cultured with Silver barb, compared to monoculture of GIFT.

Table 2. Mean (± SD) and range of water quality parameters measured in different treatments during 201 days of culture period

Parameter	T1 (FVB + Fish + Feed)	T2 (FVB + Fish)	T3 (Fish + Feed)
Temperature (ºC)	30.63 ± 1.81	30.76 ± 2.16	30.89 ± 2.11
	(28.70 – 33.70)	(28.80 – 35.20)	(28.70 – 34.80)
DO (mg/L)	4.27 ± 1.71^{b}	4.68 ± 1.47^{b}	6.52 ± 0.93^{a}
	(1.60 – 7.20)	(2.5 – 7.20)	(5.0 – 8.00)
pH	6.72 ± 0.77	6.85 ± 0.72	6.81 ± 0.74
	(6.00 – 7.70)	(6.10 – 7.90)	(6.10 – 7.81)
Ammonia (mg/L)	0.14 ± 0.10^{b}	0.11 ± 0.09^{b}	0.06 ± 0.05^{a}
	(0.01 – 0. 30)	(0.01 – 0.25)	(0.01 – 0.13)

Values in rows with different superscript letters are significantly different ($P < 0.05$).

Table 3. Mean (± sd) values of growth and production parameters of tilapia and silver barb in different treatments for 201 days of culture period

Growth and production parameter	Treatment		
	T1 FVB + Fish + Feed	T2 FVB + Fish	T3 Fish + Feed
Tilapia			
Stocking length (cm)	8.77 ± 1.24	8.79 ± 1.24	8.77 ± 1.24
Harvesting length (cm)	22.88 ± 0.17[a]	18.15 ± 0.91[b]	19.53 ± 0.71[b]
Length gain (cm)	14.11 ± 1.07[a]	9.36 ± 0.33[b]	10.76 ± 0.53[b]
Stocking weight (in g)	10.60 ± 4.6	11.17 ± 4.96	11.08 ± 5.01
Harvesting weight (in g)	244.00 ± 10.39[a]	114.27 ± 24.20[b]	141.25 ± 16.37[b]
Weight gain (in g)	233.40 ± 5.79[a]	103.10 ± 19.24[b]	130.17 ± 11.36[b]
Survival (%)	76.75 ± 3.85[a]	75.03 ± 14.68[a]	62.40 ± 5.34[a]
Daily weight gain (g/day)	1.17 ± 0.05[a]	0.51 ± 0.12[b]	0.65 ± 0.08[b]
SGR (%/day)	1.56 ± 0.02[a]	1.15 ± 0.10[b]	1.27 ± 0.06[b]
Gross production (kg/dec)	11.46 ± 0.65[a]	5.24 ± 1.58[b]	5.37 ± 0.83[b]
Silver barb			
Stocking length (cm)	7.20 ± 2.09	7.20 ± 2.12	7.20 ± 2.19
Harvesting length (cm)	25.38 ± 0.17[a]	20.60 ± 0.71[c]	21.82 ± 0.39[b]
Length gain (cm)	18.18 ± 1.92[a]	13.4 ± 1.41[c]	14.62 ± 1.80[b]
Stocking weight (g)	5.40 ± 3.74	5.27 ± 3.75	5.00 ± 3.80
Harvesting weight (g)	243.22 ± 8.19[a]	124.38 ± 7.74[c]	145.17 ± 18.49[b]
Weight gain (g)	237.82 ± 4.45[a]	119.11±3.99[c]	140.17±14.69[b]
Survival (%)	70.08 ± 3.85[a]	67.11 ± 7.46[a]	62.37 ± 5.82[a]
Daily weight gain (g/day)	1.18 ± 0.04[a]	0.59 ± 0.04[c]	0.70 ± 0.10[b]
SGR (%/day)	1.89 ± 0.05[a]	1.57 ± 0.04[c]	1.67 ± 0.07[b]
Gross production (kg/dec)	10.25 ± 0.53[a]	5.03 ± 0.67[b]	5.43 ± 0.88[b]

Mean values with different superscript letters in the same row indicate significant difference at 5% significant level.

In the present study, growth of both GIFT and silver barb was similar and significantly highest in ponds with FVB and feed application (T1). The results indicate that the addition of floating vegetable bed in closed pond might have positive effects on the growth of tilapia and silver barb. Though there had been a decrease in DO at 80 days and increase in ammonia level at 120 days of the culture period, that might have not adversely affected neither the growth nor the survival rate of fish (Table 3). At the end of the study, the SGR (%/day) attained by GIFT (1.56 ± 0.02) and silver barb (1.89 ± 0.05) was significantly higher with T1 (Table 3), corresponding to the increased growth increment during the culture period. It was recorded that the growth increment of both species in all treatments was slower for the period during 90-120 days of culture period, which might have been due to variations in DO and ammonia to its lowest and highest concentration, respectively. However, the SGR for GIFT (1.15 ± 0.10 to 1.56 ± 0.02%/day) was consistent with that has been reported as 1.76 to 2.05%/day for GIFT (Wahab *et al.*, 2019), but higher than 0.91 ± 0.02 to 1.13 ± 0.03%/day (Alam *et al.*, 2014). The SGR of silver barb (1.57 ± 0.04 to 1.89 ± 0.05%/day) in the present study was higher than that (1.33 to 1.35%/day) has been reported by (Kohinoor *et al.*, 1999). Though tilapia are known to having higher tolerance level to the variable environmental conditions (Chowdhury *et al.*, 2017; Siddik *et al.*, 2014), silver barb in present culture conditions had shown a similar or higher performance in terms of survival rate and specific growth rate (Table 3).

The gross production of cultured fish species either alone (GIFT, 2,830 kg/ha; Silver barb, 2,532 kg/ha) or in total (5,362 kg/ha) was significantly higher in T1 where the ponds had floating vegetable beds (FVB) and fish were fed. In contrast, ponds having only FVB (T2) and no FVB but received feed (T3) resulted in similar total production ranging from 2,536 – 2,668 kg/ha (Table 3; Fig. 1). The overall growth and production results indicate that cultured fish conceived some added nutritional advantages from FVB. The growth of fish and production as well in captive condition greatly depend on physico-chemical and biological water quality parameters (Shahin *et al.*, 2011). While the physico-chemical parameters were within the suitable limit (Table 2), the abundance of plankton ($19.49 \pm 1.95 \times 10^3$ cell/l) was significantly higher ($p < 0.05$) in T1 that might have been due to a combined effect of FVB and application of feed. The pond with FVB (T1 and T2) showed significantly higher ($p < 0.05$) zooplankton abundance (Fig. 2). The decomposition of organic matter of FVBs might have favoured the abundant zooplankton growth and in turn the growth and production of cultured fish species. The higher growth of periphyton in ponds with the treatment T1 than with T2 (Fig. 3) might have been due to the additional effects of organic fertilization by leftover fish feed.In an integrated fish culture hydroponic agriculture system, decaying organic material can help fertilize ponds and at the same time provide a plant growing environment less prone to diseases and soil pests (Pantanella, 2008).

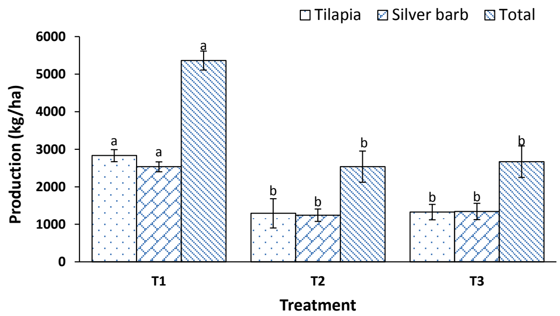

Fig. 1. Average production (kg/ha) of Tilapia, Silver barb and their total in different treatments in 201 days of culture period.

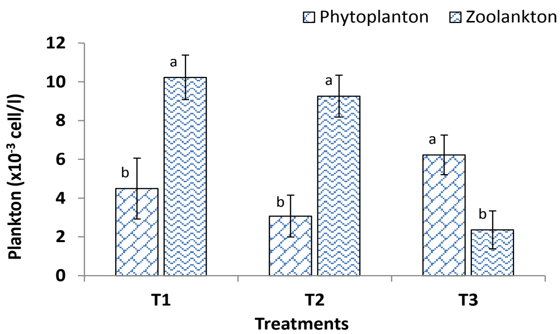

Fig. 2. Mean abundance of plankton in different treatments.

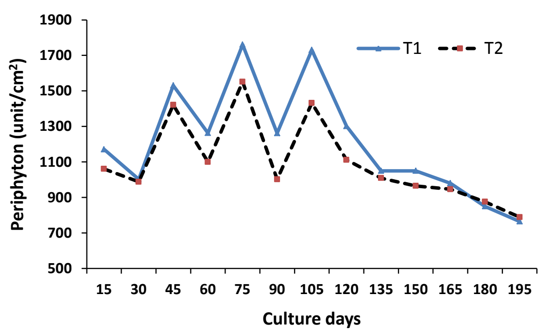

Fig. 3. Variations in periphyton in two treatments having floating vegetable bed.

The floating bed materials also provided substratum for the growth of periphyton varied from 996 to 1637 units/cm^2. The gut contents of tilapia and silver barb from each treatment were mainly composed of different groups of phytoplankton, with a robust selectivity on Bacillariophyceae, and detritus and insect remains (Table 4). However, according to Ivelv's index results of both species exhibited strong selectivity to detritus and insect remains in T1 and T2 (Table 4), where FVBs facilitated a luxuriant growth of periphyton in the forms of aggregated plankton biomass, detritus and insect larvae. A decrease in periphyton concentration, with the progress of culture period, also suggests that the grazing intensity on periphyton increased with the increase in fish growth (Fig. 3). Similar results were obtained by Kaggwa *et al.* (2009); Mbonde, *et al.* (2017) who found that the stomach contents of *O. niloticus* were dominated by detritus and algal material. While tilapia is specialized to feed on periphytic detrital aggregate, silver barb tend to consume aquatic macrophytes and mollusks (Haroon and Pitman 2000). The selection of Bacillariophyceae and detritus in both culture systems is due to their relatively larger size (Mbonde *et al.*, 2017).

Table 4. Electivity indices (Ivlev's indices) of food items consumed by tilapia (GIFT) and silver barb (SB) cultured in different treatments

Food items	Ivelv's index (E)					
	T1		T2		T3	
	GIFT	SB	GIFT	SB	GIFT	SB
Bacillariophyceae	0.68	0.51	0.74	0.61	0.74	0.66
Chlorophyceae	0.07	0.20	0.06	0.18	0.12	0.20
Cyanophyceae	-	-	-	-	-	-
	0.54	0.15	0.34	0.24	0.23	0.14
Euglenophyceae	0.10	0.59	0.13	0.43	0.18	0.59
Crustacea	0.15	0.02	0.19	0.03	0.04	0.01
Rotifera	0.08	0.11	0.05	0.08	0.02	0.04
Detritus and insect remains	0.95	0.89	0.94	0.85	0.53	0.47

Generally, while the interaction of fish with its environment and available food is recognized as the most important aspect in aquaculture (Wahab *et al.*, 2011), optimum growth of fish can only be obtained using appropriate combinations of species that utilize available resources efficiently in the pond system (Milstein *et al.*, 2009). The present study showed similar growth performance between GIFT (*O. niloticus*) and silver barb (*B. gonionotus*) raised in pond with floating vegetable bed (FVB), despite of their similar herbivorous and detritivorous feeding habits (Ssanyu *et al.*, 2011). Based on the present environmental conditions and growth performance of both culture species, it could be assumed that both species efficiently utilized available foods through synergistic relationships while minimizing antagonistic ones, as has been suggested by Milstein *et al.* (2009).

Table 5. Production of vegetable grown on floating bed from each floating bed (4.5m x 1.5m)

Name of vegetables	Production (kg/m^2)	
	T1 (Fish + FBV + Feed)	T2 (Fish + FBV)
Swamp cabbage (*Ipomoea aquatica*)	8.99 ± 0.51	9.01 ± 0.34
Okra (*Abelmoschus esculentus*)	2.87 ± 0.25	2.65 ± 0.41
Indian spinach (*Basella alba*)	7.24 ± 0.62	7.12 ± 78
Water taro (*Colocasia esculenta*)	2.65 ± 0.47	2.83 ± 38

Table 6. Average cost and benefit from 130 m² pond and 6.75 m² bed area under different treatments

Item	T1 (Fish + FBV + Feed)	T2 (Fish + FBV)	T3 (Fish + Feed)
Cost in Taka			
1. Preparation of floating bed	700.00	700.00	
2. Vegetable seedling	200.00	200.00	
3. Fish fingerling	1,170.00	1,170.00	1,170.00
4. Fish feed	2,000.00	-	2,000.00
Total cost	4,070.00	2,070.00	3,170.00
Income in Taka			
Sale price of vegetables			
1. Swamp cabbage (@ Tk. 15/kg)	227.85	229.45	
2. Okra ((@ Tk. 20/kg)	97.00	96.25	
3. Indian spinach (@ Tk. 15/kg)	183.60	182.89	
4. Water taro (@ Tk. 15/kg)	67.20	68.24	
Sub-total	575.65	576.83	
Sale price fish (@120/kg)	8,467.20	4,005.60	4,212.00
Total income in Taka	9,042.85	4,582.25	4,212.00
Net benefit in Taka	4972.85	2512.43	1042.00

Harvest weights of different vegetables per unit area are shown in Table 5. According to the yield rate, the best-performed vegetable was swamp cabbage (kolmi shak) with an average harvest of 360.40 kg/decimal (9.01 kg/m^2) followed by, Indian spinach, with an average harvest of 289.60 kg/decimal (7.24 kg/m^2). Aquatic effluents resulting from uneaten feed or raising animals like fish were used to supply nutrients essential for plant growth (Das 2012). The yield rates of vegetable in the aggregated hydroponic system in the present study are comparable with findings of Rakocy *et al.*, (2004) who reported an annual yield of basil (Indian spinach) 7.8 kg/m^2 and okra 2.54 kg/m^2 from low and 2.89 kg/m^2 from high density planting in aquaponic practices.

A simple cost-benefit estimation showed that The gross income from fish (BDT 8467.20) and net benefit (BDT 3972.85) was the highest with the integration of floating bed cultivation (aggregate hydroponic) and aquaculture in pond, where feed was applied to fish (T1) (Table 6). Though the total production of vegetable and income was similar for T1 and T2, the net benefit was higher in T1 due to higher income from fish (Table 6). Besides, in T3 where only feed was used to fish, the net benefit was 4.78 and 2.41 times lower than T1and T2, respectively. The results indicate that integration of fish culture with vegetable production in floating bed may increase higher net economic benefit compared to the conventional fish culture system.

Conclusions

One of the leading principles in sustainable aquaculture is the increased production with reduced ecological impact. One way to comply with this principle is integration between production systems and reduced use of chemicals. The present study showed that the potentials of integrating fish culture with aggregated hydroponic vegetable production system applying a lower amount of fish feed and no use of chemicals to pond water and vegetables, but obtaining a higher and diversified outputs of fish and vegetables. The design and management of the system are very simple and promising wherever land availability, flooding, productivity and ecological footprint are of concern. The system may turn floating bed agriculture into a working model of sustainable food production concurrently using available rural ponds. The possibilities of adoption are quite high, offering sensitive benefits to small as well as large scale farmers in terms of household income and nutrition. However, to harness the full potential of the system, interdisciplinary link and research are needed to address many of the issues relating to fish culture and vegetable production, optimizing vegetable bed size in proportion to the pond area, detailed nutrient dynamics and those are still unattended.

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Declaration

The authors declare that research results reported in this article do not have any conflicting interest.

Author's Contribution

M. J. Alam: Research concept development, planning and designing, final data analysis, supervision, writing the manuscript; H Yasmin: Conducting experiment, data recording and compilation. M. S. Hossain and M. S. Alam: Constructive suggestion in research implementation, review and editing the manuscript.

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