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Integrated floating cage aquageoponics system (IFCAS): An innovation in fish and vegetable production for shaded ponds in Bangladesh

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ABSTRACT

Farmer participatory action research was carried out from July to December 2013 to design and construct a technology known as IFCAS (integrated floating cage aquageoponics system) for growing fish and vegetables in shaded ponds in the Barisal region of Bangladesh under the EU funded ANEP (Agriculture and Nutrition Extension Project). Here the terms aqua, geo and ponics means pond water, pond mud/soil and cultivation, respectively. Producing and regularly harvesting fish in shaded ponds and growing vegetables on surrounding dykes for household consumption was constrained. To overcome the difficulties, an IFCAS ($3.66\,\text{m} \times 2.44\,\text{m} = 9\,\text{m}^2$) was set in each of 9 shaded ponds – 5 highly shaded ponds (HSP) and 4 moderately shaded ponds (MSP) – in which GIFT tilapia strain (*Orechromis niloticus*) was stocked at the rate of $100\,\text{m}^{-3}$ cage. In the ponds, carp species (*Catla catla*, *Labeo rohita*, *Cirrhinus cirrhosus* and *Cyprinus carpio*) were stocked at the ratio of 1:2:2:1, and at the rate of $14{,}820\,\text{ha}^{-1}$. Tilapia were fed floating feed and the carp were fed with supplementary feed. Vegetables were grown on the IFCAS scaffold, and tilapia were grown in the net-cage constructed underneath. Women members of HSP households participated fully in the action research in the production of vegetables and fish in IFCAS. Participating households started consuming vegetables and tilapia from IFCAS within 1.5 and 1 month of the start of the experiment, respectively. Average fish consumption of $20\,\text{kg}\,\text{household}^{-1}$ was recorded within four months, of which more than 50% was tilapia from IFCAS. Overall fish and vegetable production was higher in MSP as compared to HSP. A financial analysis showed the benefit-cost ratio of IFCAS was >1, indicating the investment efficiency of IFCAS for farmers.

1. Introduction

Bangladesh is considered one of the most suitable countries in the world for freshwater fish production because of its deltaic nature with favorable resources and agro-ecological conditions. The country is blessed with numerous water bodies including rivers, *beel* (natural depressions), flood plains, lakes, ponds, ox-bow lakes, etc., which contain 260 different species of fish (Rahman, 1989). However, the growth of inland capture fisheries production has been limited by a variety of factors including habitat loss as a result of agricultural intensification, urbanization, environmental degradation, pollution, and overexploitation of resources (Belton et al., 2011). For example, in 2001–2002, inland capture fisheries contributed 36.42% of total fish production whereas in 2012–2013, it was 28.19% (DoF, 2014). In contrast, fish supply from aquaculture has increased rapidly in Bangladesh over the last two decades. This trend is similar to that in many other Asian countries, including China, India, Philippines, Thailand, Vietnam and Indonesia, where aquaculture is an increasingly important source of animal protein and contributes to the food security of millions (Ahmed and Lorica, 2002; Belton et al., 2011).

Currently, fish production plays an important role in the people's daily diet, contributing 60% of national animal protein supply, representing a crucial source of micro-nutrients (DoF, 2014). Moreover, it plays an important role in the economy of Bangladesh, contributing to generating livelihoods opportunities and to earning foreign currency (Haque et al., 2014). According to recent statistics, fish accounts for 4.37% of gross domestic product and 2.01% of export earnings (DoF, 2014). Fish are produced in a variety of production systems, but ponds are by far the most important,

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accounting for more than 78% of total production in 2012–2013. Regionally, pond aquaculture production has developed tremendously in the north-central and south-east regions of Bangladesh, most notably in Mymensingh and Jessore districts (DoF, 2014). This is mainly due to access to advanced aquaculture technologies and markets, and availability of fish seed, fish feed and other necessary production inputs.

Like other areas of Bangladesh, rural households in Barisal region have perennial ponds which were mainly excavated originally as borrow pits in order to raise the level of homesteads to avoid flooding (Rahman et al., 1992). Traditionally these sorts of ponds were used as trap ponds for fish, with limited stocking of carp fry, and were mainly used for subsistence consumption (Rahman et al., 1992). However, trap pond production has reduced over the years and the abundance of wild fish has declined. In this context, aquaculture has increasingly compensated for the gap between fish supply and demand in Barisal region (Fig. 1).

Barisal district is a part of the south-central region of Bangladesh, located on the northern shore of the Bay of Bengal, which was developed by the alluvial flow of the Kirtankhola River (Fig. 2). Although Barisal is just 112 km away from the capital city of Dhaka, due to the large number of rivers between these locations, Barisal remains far away from mainstream development. The livelihoods of a considerable proportion of rural people depend entirely on fishing in inland open water bodies (mainly rivers and canals) and the sea, and poverty levels are particularly high. The EU funded ANEP (Agriculture and Nutrition Extension Project) was implemented in Barisal district from 2012 to 2014 in order to help increase fish production and improve household nutrition, following an integrated aquaculture-agriculture approach. WorldFish implemented the aquaculture component of ANEP in collaboration with other partners. Pond dykes in Barisal are commonly used for planting trees which provide cooking fuel, fruits, and timber for sale. Trees on the pond dyke create shadow, which reduces sunlight penetration to the edges of the pond and the dykes. Moreover, these kinds of ponds are often deep and irregular in shape, making it is difficult to harvest carp from deeper ponds during the peak monsoon season (June–September). All of these aspects negatively impact potential for fish and vegetable production. However, the sunlight exposed areas of the pond water have the potential for growing vegetables. Considering this potential, an action research component of the project trialled an IFCAS (integrating floating cage aquageoponics system), alongside an improved carp polyculture system. IFCAS was designed to complement this project intervention by ensuring an early and regular supply of fish (tilapia) and vegetables to farming households for home consumption. The improved carp polyculture in the pond was expected to increase pond production, nutritional benefits and income at the end of the season when the pond is harvested completely.

1.1. Conceptual model of IFCAS

IFCAS was developed following the principles of action research (Biggs, 1989), whereby men and women farmers from pond owning households participated collegially with researchers and development workers (NGO staff) to design and refine the IFCAS technology for shaded ponds, without changing the vegetative nature of pond dykes. In integrated farming systems, an output from one subsystem which may otherwise have been wasted becomes an input to another sub-system, resulting in a greater efficiency of output of desired products from the land/water area under the farmer's control (Edwards, 1998). Cages utilize existing water resources to raise fish, but enclose them in a cage or basket which allows water to pass freely between the fish and the pond (Masser, 1988). In aquaponics systems, the waste produced by farmed fish supplies nutrients for plants grown hydroponically, which in turn purify the water. The plant growing media in aquaponics can be soil, coconut fiber, gravel etc., but these are not used for plant nutrient supply (Sirsat and Neal, 2013). Generally aquaponics is thought of as a soilless production system, but some recent literature indicates that soil can be used as media for aquaponics plants (Mader, 2012; Shanbhag, 2014). In the IFCAS, dried pond mud collected from the same pond was used as a holding medium for plants. As this provides supplementary nutrients, the system is therefore most correctly termed as aquageoponics, where aqua, geo and ponics means pond water, pond mud/soil and cultivation, respectively.

Considering the context above, this article attempts to assess how this integrated technology fits into the socio-economic conditions of farming households and physical characteristics of the pond. It also assesses fish and vegetable production and household level consumption, and financial efficiency of IFCAS.

2. Material and methods

2.1. Features of the study area

Barisal region occupies an extensive area of tidal floodplain lowland where the soil is generally sandy loam to loam in nature, but the percentage of clay in soil is much higher than in other parts of Bangladesh. The low-lying nature of land in the region has compelled people to raise the level of their homesteads to higher

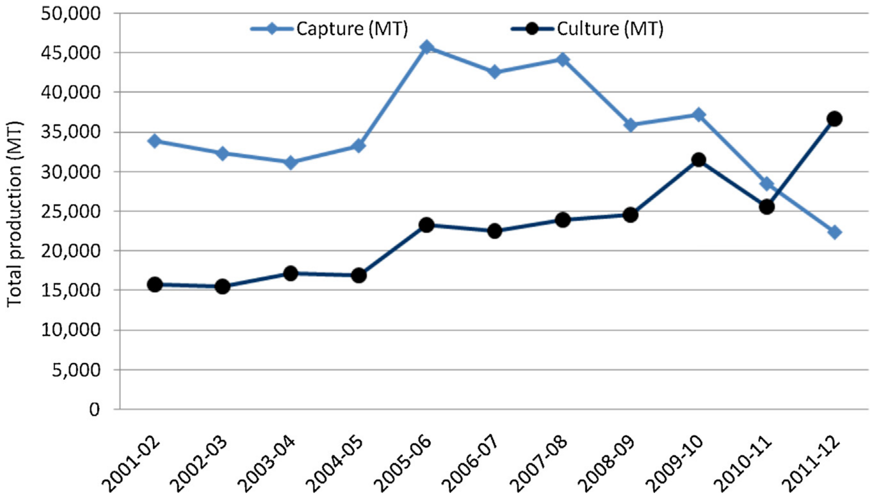

Fig. 1. Fish production from capture fisheries and aquaculture during the period 2001–2012 in Barisal district.
Source: Adapted from FRSS (2001–2002) to FRSS (2011–2012) and DoF, 2014.

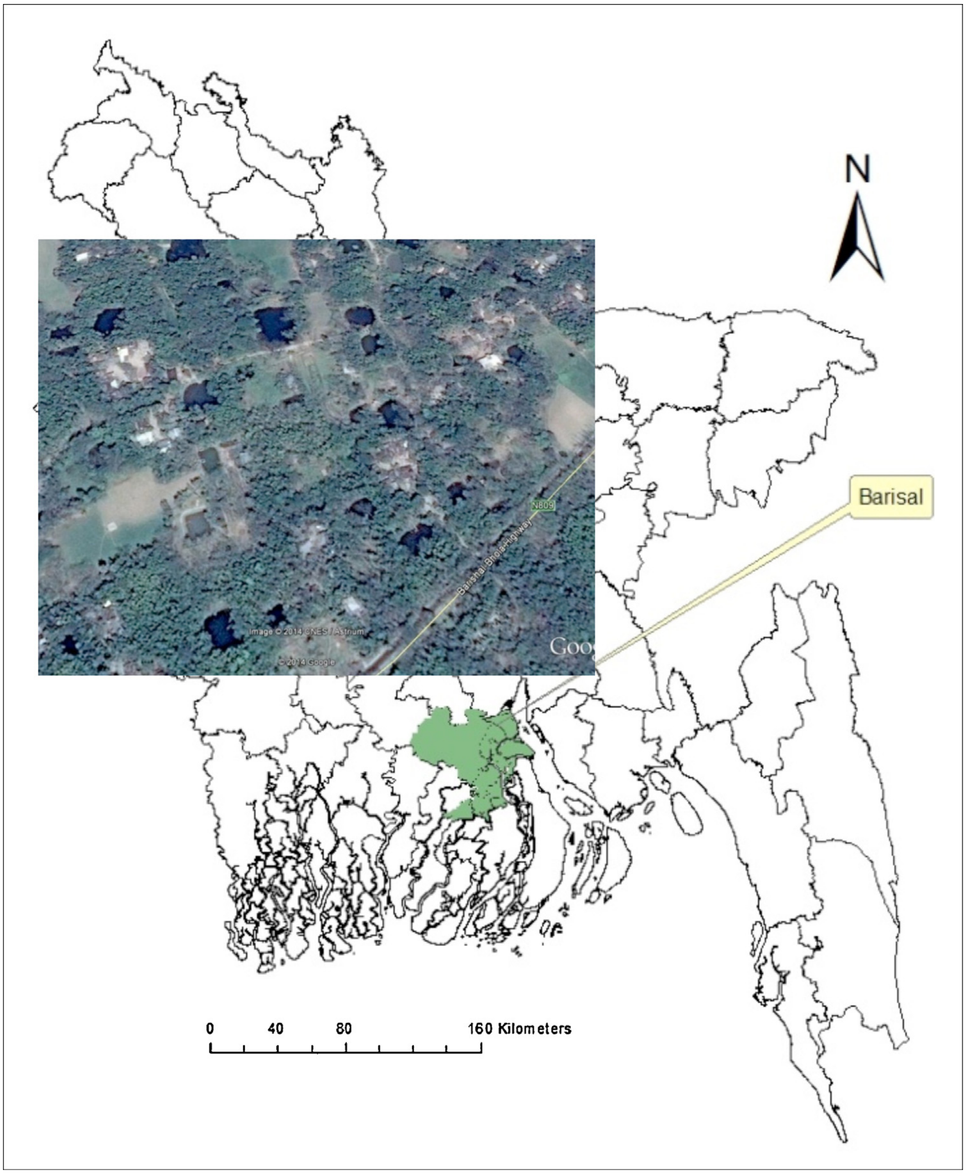

Fig. 2. Map of Bangladesh showing Barisal district, with an embedded Google Earth image of the study village, showing shaded ponds.

elevations in order to avoid flooding. The excavation of soil for this purpose has resulted in the construction of ponds which are irregular in shape and depth and surrounded by variety of trees (Fig. 2). Clay soil becomes hard during dry season, making it difficult to grow vegetables. Prolonged drizzling during monsoon makes homestead soil muddy and sometimes inundated, and also causes difficulties for growing vegetables (iDE, 2009).

2.2. Experiment site and pond preparation

This action research started from July 2013 by selecting 9 households from Dinar village, in Charkawa Union of Barisal Sadar sub-district. Initially the basic socio-economic data of the selected households was collected to assess the impacts of the technology at the end of trial. Selection of households for the trial was based on a variety of criteria, including having shaded ponds adjacent to their homesteads, the willingness of household members to participate, and sharing of input costs for the action research. The project provided the basic structure of IFCAS frames and fish fingerlings to the farmers. However, farmers shared 40% of the total feed cost. Out of nine farmers, five had heavily shaded ponds (HSP) and four had moderately shaded ponds (MSP), with an average area of 0.03 ± 0.01 and 0.07 ± 0.03 ha, respectively. The depth of the ponds ranged from 2 to 3 m during June–November, with irregular bottom topography. The characteristics for HSP included; small water surface area, the whole dyke covered by trees, sunlight exposure in the middle of the surface area only, and inability to produce vegetables on the dykes due to lack of sunlight exposure. MSP have a relatively larger surface area, a major proportion of dyke covered by trees, and sunlight exposure on a larger proportion of the water surface. Farmers cannot plant vegetables on MSP dykes, due to the presence of the roots of large trees. In the first week of July 2013, undesirable aquatic vegetation and floating debris were manually removed from the trial ponds. Following this, pond water was treated with lime at the rate of 247 kg ha^{-1}.

2.3. Setting up the IFCAS

A 9 m^2 rectangular iron-bar made structure was constructed, having four concave grooves in its four corners for holding floats of plastic drums. The whole bottom of the structure was surrounded by a rectangular nylon net cage with the dimensions

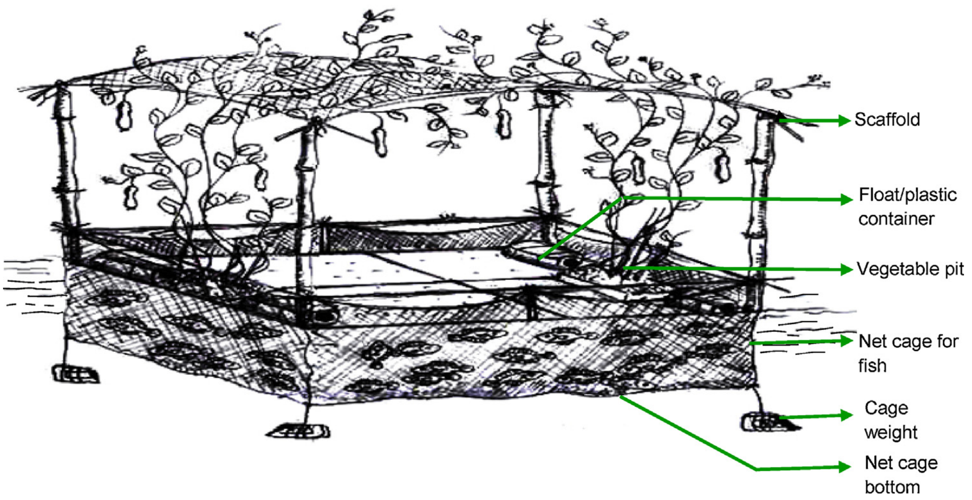

Fig. 3. Sketch of IFCAS showing different systems components.

of length-3.66 m × width-2.44 m × depth-1.25 m (Fig. 3). Two pits, one at each width end of the IFCAS structure were filled with a mixture (medium) of 70% dried pond mud from the same pond and 30% cow dung, for vegetable plantation. The dimensions of each pit were 0.61 m × 0.51 m × 0.20 m, and 20% of the soil in each pit (about 4 cm depth) was in contact with the pond water so that vegetables roots could easily take up nutrients. Half-brick weights were hung under the four corners and the center of the net, to ensure that the net retained a rectangular structure under water. A scaffold was made on the top of the structure using split bamboo and net for vegetables to climb on. The IFCAS in pond occupied about 3% (9 out 300 m^2) and 1.28% (9 out of 700 m^2) of the pond surface area in HSP and MSP, respectively.

All 9 IFCAS were set in the sunlight exposed area of pond by farmers themselves. Farmers made some changes to the original IFCAS design where the scaffold size was 3.66 m × 2.44 m × 0.4 m. The height and size of scaffold was elevated and extended, respectively, using split bamboo to enlarge the vegetable growing space and to facilitate growing long vegetables (e.g., gourds, which can reach up to 50 cm in length). Feeding fish in the cages of IFCAS and ponds was a daily activity, and taking care of vegetable plants on the pit of IFCAS was the weekly activity. The level of participation by women was encouraging, and was greatest among those with HSP households.

2.4. Assessing pond water quality parameters

The water quality parameters including temperature (using Celsius thermometer), dissolved oxygen, pH, NH_3 and NO_2 were measured by HACH kit (model FF-1A, Cat No. 2430-02). These analyses were carried out on the pond side at the beginning and end of the trial in mid July and mid-November 2013, respectively, between 9:00 and 10:00 am.

2.5. Fish stocking and pond management

Monosex fry of improved (GIFT strain) tilapia (*Oreochromis niloticus*) were stocked for four months (from mid-July to mid-November 2013) in the 9 m^2 net cage at the rate of 100 m^{-2}, and then fed commercial floating feed containing 28–30% of crude protein. Farmers were recommended to feed tilapia twice a day in the early morning and afternoon depending on the body weight of the stock. In the first (from mid-July to mid-September) and last (from mid-September to mid-November) two months, feeding was done to satiation (ad libitum) at the rate of 20% and 15% of the body weight of tilapia, respectively. A long spoon-like device was made with a bamboo stick and small plastic mug so that both men and women could very easily provide feed for tilapia in the cage from the pond dyke. The net cage of IFCAS was checked daily to ensure ad libitum and minimize feed wastage. At the same time of stocking tilapia in IFCAS, carp were stocked both in HSP and MSP at the rate of 14,820 ha^{-1}, in a polyculture of catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus cirrhosus*) and common carp (*Cyprinus carpio*) at the ratio of 1:2:2:1. Additionally, in HSP stinging catfish (*Heteropneustes fossilis*) was stocked at the rate of 1235 ha^{-1}. This was done to observe its growth performance in HSP since there is a belief that stinging catfish can grow well in the dark conditions. The carp were fed with supplementary feed of the mixture of rice bran, wheat bran and mustard oilcake which was broadcast at the rate of 10% body weight for first 3 months (from mid-July to mid-October) and 5% body weight for last 2 months (from mid-October to mid-December). To enhance the growth of natural food for the carp, pond fertilization was carried out with urea (400 kg ha^{-1}) and TSP (200 kg ha^{-1}) once a month. During the winter months (November and December), lime and salt was used at the rate of 247 kg ha^{-1} to improve water quality and prevent fish diseases.

2.6. Recording data on fish and vegetable production, consumption and adoption

During the experimental period, quantitative and qualitative data regarding fish growth in IFCAS and pond, vegetable production, fish and vegetable consumption, sales and farmers' adoption of IFCAS were recorded regularly. Fish were sampled at monthly intervals and measured to determine length and weight, using a ruler and electronic balance (Model HKD-620AS-LED). Fish and vegetable production and consumption data were recorded by farmers, which promoted a better understanding of the overall impacts of the technology.

2.7. Data analysis

The data generated from field trials were analyzed using statistical software SPSS (Statistical Package for Social Sciences) version 16. An independent sample *T*-test (Field, 2005) was done to assess the differences between HSP and MSP in terms of household characteristics, tilapia and vegetable production in IFCAS, fish production in pond, and water quality parameters. Moreover, a tabular financial analysis was done to assess the economic viability of IFCAS for farmers (Shang, 1990). All cost items were considered in this

Table 1
Socio-economic characteristics (mean ± SE) of IFCAS practicing households.

Characteristics	HSP ($n = 5$)	MSP ($n = 4$)
Average age of household head (mean ± SE)	48 ± 4.36	33.75 ± 3.75
Education level of household head (frequency)		
Illiterate	1	–
Primary	1	2
Secondary	–	1
SSC–HSC	1	1
Bachelor	2	–
Occupation of household head (frequency)		
Agriculture	–	2
Small job (office peon, shopkeeper, bus conductor and foreign migrant worker)	5	1
Petty business (grocery shop)	–	1
Average household size (no ± SE hh^{-1})		
Total number of family members	4.4 ± 0.24	6.5 ± 1.70
Number of males	2.2 ± 0.37	2.5 ± 0.98
Number of females	2.2 ± 0.37	4.0 ± 1.0
Number of income earners	1.8 ± 0.37	2 ± 0.58
No of school going children	1.8 ± 0.20	2 ± 0.71
Average landholding (ha ± SE hh^{-1})		
Own	0.33 ± 0.11	0.28 ± 0.11
Leased-in		0.34 ± 0.15
Multi-ownership	0.75 ± 0.47	0.65 ± 0.16
IFCAS pond characteristics (mean ± SE)		
Pond area including dike (ha)	0.04 ± 0.01	0.08 ± 0.03
Pond water area excluding dike (ha)	0.03 ± 0.01	0.07 ± 0.03
Pond depth (m)	3.29 ± 0.31	3.35 ± 0.17
Maximum water depth in monsoon (m)	2.68 ± 0.27	2.89 ± 0.12
Minimum water depth in monsoon (m)	2.38 ± 0.24	2.44 ± 0.08
Area of pond water receiving sunlight (ha)	0.01 ± 0.01	0.03 ± 0.01
Distance of pond from owner's house (m)	7.1 ± 1.74	9.9 ± 2.53
Average income per year (US$ ± SE hh^{-1})	2005.00 ± 678.88	1890.61 ± 580.94

hh – Household; SE – standard error; ha – hectare; m – meter; USD 1.00 – BDT 80.00.

analysis, except for operational labor inputs because these were supplied by the farmers themselves as part of the action research. The construction materials such as floating plastic drums, iron bars and nets were all purchased locally, and construction of IFCAS was carried out using welding shop services in the local marketplace.

3. Results

3.1. Household characteristics and their participation in the action research

The average age of the HSP household heads (48 ± 4.36 years) was significantly higher ($p < 0.05$) than that (33.75 ± 3.75) of MSP household heads, but all were classed as middle aged, considering the population of Bangladesh (Table 1). Heads of HSP households were found to be more educated than those of MSP households, and for this reason HSP household heads tended to be employees in small jobs and businesses. Agriculture was the main occupation of MSP households, and their household size was significantly larger ($p < 0.05$) than that of HSP. There was no significant difference ($p > 0.05$) in the size of landholdings owned by HSP and MSP households, but because of their involvement in agriculture, MSP households leased in additional land (0.34 ± 0.15 ha). The annual income of HSP households was not significantly higher ($p > 0.05$) than that of MSP households, but due to doing at least one additional job, MSP households had relatively higher annual income.

3.2. Growth and production of fish and its consumption at household level

The survival of tilapia in the IFCAS cage was similar in both HSP (48.61%) and MSP (49.13%). However, there was a significant difference ($p < 0.05$) found between the IFCAS of HSP and MSP for individual growth of tilapia (Table 2). The average size of tilapia in IFCAS was 76.2 ± 8.3 and 112.3 ± 37.9 g, respectively, in HSP and MSP after four months, where the initial weight was 0.73 g. The production of tilapia in IFCAS and carp in ponds was significantly higher ($p < 0.05$) in MSP than in HSP. The average total production of tilapia in IFCAS (kg 9 m^{-2}) was 31.2 ± 4.4 and 52.2 ± 25.9 kg in HSP and MSP, respectively. The individual growth of rohu and mrigal was significantly higher ($p < 0.05$) in MSP than in HSP (Table 2). However, the individual growth of the bottom feeder, common carp was significantly higher ($p < 0.05$) in HSP compared to MSP. The productivity of carp in ponds was estimated based on the reference value of 70% survival of carp in polyculture systems in Bangladesh, as reported by ADB (2005). Complete harvest was not possible due to difficulty of netting deeper and irregular shape of ponds, the high expense of pumping out the water, and reluctance of farmers to do this. The estimated productivity of carp in HSP was lower than MSP (Table 2). The growth of stinging catfish was not comparable between the types of ponds (as it was only stocked in HSP), but it was found to grow well in HSP, indicating potential for growth and production in MSP too. There was no any significant difference ($p > 0.05$) in fish consumption from IFCAS and ponds between HSP and MSP households. Irrespective of the shaded nature of the ponds, total fish consumption from IFCAS and pond for four months was more than 20 kg household^{-1}. Per capita consumption of fish originating from IFCAS and pond was 4.55 and 3.23 kg in HSP and MSP households, respectively. Fish produced in IFCAS (tilapia) accounted for more than 50% of the total fish consumed from pond resources (Fig. 4). The remaining large size tilapia produced from IFCAS was sold to local fish traders and smaller ones were stocked in the ponds at the end of the experiment. Stocked carp along with small tilapia were remained in the

Table 2
Growth and production (mean ± SE) of tilapia and vegetable in IFCAS, and carp in pond.

Growth and production	Initial weight (g) of fish	Final weight (g) of fish		*T*-test *p*-value	Culture period (no. of months)
		HSP ($n = 5$)	MSP ($n = 4$)		
Individual growth (mean ± SE)					
Tilapia in IFCAS (g)	0.73	76.2 ± 8.3	112.3 ± 37.9	0.002*	4
Catla in pond (g)	3.36	373.4 ± 122.23	409.6 ± 121.9	0.151	5
Rohu in pond (g)	2.37	188.1 ± 22.9	235.1 ± 41.2	0.030*	5
Mrigal in pond (g)	2.54	175.0 ± 26.8	220.1 ± 75.8	0.010*	5
Common carp in pond (g)	3.00	470.0 ± 3.2	390.4 ± 80.2	0.021*	5
Stinging catfish in pond (g)	0.60	75.5 ± 6.3	–	–	5
Total production of fish					
Tilapia in IFCAS (kg 9 m^{-2} 4 months^{-1})		31.2 ± 4.4	52.2 ± 25.9	0.003*	4
Carp in pond (kg ha^{-1} 5 months^{-1})		2,470.8 ± 325.9	2,957.2 ± 754.2	0.045*	5
Stinging catfish in pond (kg ha^{-1} 5 months^{-1})		64.8 ± 12.5	–		5
Vegetable production in IFCAS					
Vegetable production (kg 9 m^{-2} 4 months^{-1})		13.1 ± 2.4	16.8 ± 3.5	0.201	5

* Indicates significant difference between HSP and MSP at $p < 0.05$.

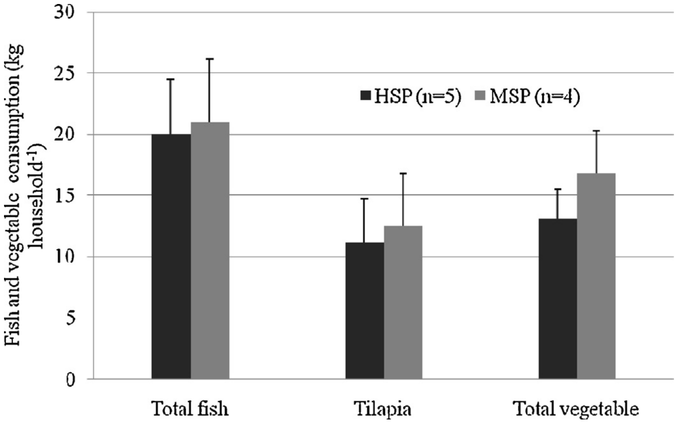

Fig. 4. Fish and vegetable consumption (mean ± SE) from IFCAS and ponds during four month trial.

ponds to make them larger in size for households' consumption and sale.

3.3. Growth and production of vegetables and its consumption at household level

The fastest growing vegetables produced in IFCAS were cucumber (*Cucumis sativus*), snake gourd (*Trichosanthes cucumerina*), Indian spinach (*Basella alba*) and tomato (*Solanum lycopersicum*). During 5 months of operation, two vegetable crops were produced, each within 2.5 months. Cucumber, snake gourd, bitter gourd (*Momordica charantia*), and Indian spinach were grown during July–September and, flat beans (*Phaseolus vulgaris*), bottle gourd (*Lagenaria siceraria*) and tomato were grown during October–December. The average total production of vegetable per IFCAS for four months in HSP and MSP (Table 2) did not differ significantly ($p > 0.05$). Consumption of vegetables from IFCAS started one and a half months after the start of the experiment. All of the vegetables produced in IFCAS (Fig. 4) were consumed by farming households themselves.

3.4. Water quality parameters

There were no major differences found in the water quality parameters of temperature, dissolved oxygen and pH between HSP and MSP at the beginning of the trial. However, significant differences ($p < 0.05$) were found between the ammonia and nitrite content of water in HSP and MSP (Table 3). At the end of experiment, water temperature was considerably reduced due to entering the winter season. However, other parameters were similar to those at the beginning of the trial.

3.5. Financial efficiency of IFCAS

Table 4 indicates the financial efficiency of IFCAS in HSP and MSP. Considering the depreciation cost of the IFCAS structure, its service cost per year is about US$ 10.98. The cost of tilapia, and vegetable production for a four month cycle has been estimated at US$ 3.66. Total gross costs including operating costs such as tilapia fingerlings and commercial feed and the fixed costs of the IFCAS amounted to US$ 37.46 and US$ 48.26 for HSP and MSP, respectively. The gross revenue considering the total farm-gate value of total tilapia and vegetable production was US$ 48.03 and US$ 84.68 for HSP and MSP, respectively. The net profit from IFCAS in MSP was higher compared to HSP. Although the investment in IFCAS was financially efficient in both types of pond, the benefit cost ratio (BCR) was higher in MSP. This was attributed to the production of large size tilapia in the later with good market price (Table 4).

4. Discussion

Participatory approaches are effective in generating and adapting new technologies for a range of natural resource based adaptive and applied research at the farmer level (Sutherland, 1998). Farmers, through their informal research activities combined with indigenous technical knowledge contribute to the development of technological innovation (Biggs and Clay, 1981). The MSP households enlarged the scaffold of their IFCAS by an average of 20% from the original size of 9 m^2, constructing the scaffold using split bamboo to enlarge the area of scaffolding at low cost. Farmers also elevated the height of the scaffold using bamboo produced in their homesteads to grow long vegetables and to make fish harvesting easier. The action research was collegial in nature with farmers having equal power to influence and contribute to the whole research process as researchers and developers.

HSP household possessed smaller ponds (and landholdings) than MSP households and were more reliant on non-farm work. The limited pond resources of HSP households, as compared to MSP possibly encouraged women in HSP to concentrate on maximizing the output of the IFCAS. Similar tendencies have been evidenced among small farmers in the case of cereal farming in many other parts of the world (Biggs, 1989). MSP households tended to be more heavily involved in agriculture occupations, and possessed larger

Table 3
Water quality parameters (mean ± SE) in HSP and MSP at the beginning and end of the experiment

Parameters	15 July 2013		15 November 2013	
	HSP	MSP	HSP	MSP
Temperature (°C)	25.60 ± 0.24	25.50 ± 0.65	22.60 ± 0.40	22.75 ± 0.85
Dissolved oxygen – DO (ppm)	5.60 ± 0.93	4.50 ± 0.87	4.20 ± 0.49	4.75 ± 0.85
pH	7.78 ± 0.11	8.23 ± 0.34	7.30 ± 0.25	7.38 ± 0.43
Ammonia – NH_3 (ppm)	0.22 ± 0.09	0.08 ± 0.05	0.22 ± 0.05	0.05 ± 0.07
Nitrate – NO_2 (ppm)	0.08 ± 0.02	0.02 ± 0.00	0.10 ± 0.03	0.02 ± 0.03

average household sizes than HSP. For these households, adoption of IFCAS provided a means to meet day to day requirements for food including fish and vegetables, and made MSP households interested in IFCAS. These two scenarios indicate that IFCAS technology was compatible with the livelihoods of both on-farm and non-farm employment dependent households.

Due to socio-cultural norms, rural women in Bangladesh do not usually travel long distances to work, but rather they take part in agricultural activities that are possible within the area of the homestead. The close proximity of ponds to the homesteads of HSP households made the operation of IFCAS more women-led than in MSP households. Women from HSP households took part in feeding fish, tending and harvesting vegetables, general oversight of the whole IFCAS, most of the time. On the other hand, the ponds operated by MSP households tended to be relatively distant from the homestead, and IFCAS in these households were operated largely by men. Thus, IFCAS proved to be suitable technology for households with a range of demographic characteristics and asset profiles.

Overall water quality parameters except temperature did not vary significantly between the beginning and end of trial. This indicates that installation of IFCAS in shaded ponds did not contribute to the deterioration of water quality possibly because IFCAS occupied a small area of the total pond surface, and vegetable plants' roots balanced water quality by absorbing nutrients for their growth, which might otherwise have proven toxic (Sirsat and Neal, 2013). Since individual growth of tilapia was higher in MSP compared to that of HSP, thus IFCAS tilapia productivity was higher in MSP. This was directly evidenced by the lower satiation level of feed intake of tilapia observed in the IFCAS of HSP compared to MSP. Reduced growth was attributed to poor water quality in HSP resulting from decomposition of the organic matter, particularly the leaves of plants from the pond dyke, which can negatively affect fish health. According to water quality testing at the beginning and end of the culture period, the content of nitrite (NO_2) was found to be higher in HSP than MSP. Only the lower of these level is acceptable at <0.02 ppm for warm water fishes (Bhatnagar and

Table 4
Financial analysis of IFCAS construction and operation for four months.

	Inputs/items/produce	Amount (weight/no.)	Unit price (US$)	Cost/revenue (US$) for HSP	Cost/revenue (US$) for MSP
A	IFCAS structure – iron bar and drum				
	Iron bar	45 kg	US$ 0.68/kg	30.60	30.60
	Plastic drum (70 L volume)	4 nos.	US$ 3.75/no.	15.00	15.00
	Plastic drum (40 L volume)	1 no.	US$ 3.13/no.	3.13	3.13
	Construction cost			8.75	8.75
	Total cost			57.48	57.48
	Per year depreciation cost (10 years of longevity)			5.75	5.75
B	IFCAS net				
	Nylon net for cage	22 m	US$ 0.40/m	8.80	8.80
	Net preparing cost			3.13	3.13
	Others including bamboo, threads etc., for scaffold			3.75	3.75
	Total cage net cost			15.68	15.68
	Per year net/scaffold depreciation cost (3 years of longevity)			5.23	5.23
C	Depreciation cost of an IFCAS structure				
	Structural cost for a year			10.98	10.98
	Structural cost for four months			3.66	3.66
D	Operating cost for IFCAS				
	Fingerling of tilapia	900 nos.	US$ 0.013/no.	11.70	11.70
	Feed	36 kg – HSP; 54 kg – MSP	US$ 0.60/kg	21.60	32.40
	Vegetable seed/seedlings			0.50	0.50
	Total operating cost for IFCAS			33.80	44.60
	Gross cost			37.46	48.26
E	Revenue from IFCAS				
	Tilapia production in IFCAS	HSP 31.2 kg; MSP 52.2 kg	HSP US$ 1.38/kg; MSP US$ 1.50/kg	43.06	78.30
	Vegetable production	HSP 13.1 kg; MSP 16.8 kg	US$ 0.38/kg	4.98	6.38
	Gross revenue			48.03	84.68
F	Net benefit per household IFCAS^{-1}				
	Net benefit = E–D			10.57	36.42
G	Economic efficiency				
	Benefit-cost ratio (BCR) = E/D			1.28	1.75

US$ 1.00 = BDT 80.00 in December 2013.

Devi, 2013). Moreover, although light intensity does not affect fish survival, fish growth rates are significantly reduced at lower light intensities (Han et al., 2005). Light intensity and photoperiod can also have significant impacts on growth, reproduction and other biological activities of tilapia (Ridha and Cruz, 2000).

A higher level of individual fish growth was found for most carp in MSP, but common carp had higher growth in HSP. This was possibly due to availability of decomposing plant debris and insect larvae (chironomids etc.) living in the mud on pond bottom which is consumed as natural feed by the common carp (Billard, 1995). Individual growth of catla was found much higher in MSP compared to HSP, probably due to the greater abundance of plankton in the MSP. These findings indicate that catla and common carp are the most suitable species for polyculture in shaded ponds in Barisal region. The growth of high market value stinging catfish in HSP was also found to be encouraging, and suggests that stinging catfish would likely also grow well in MSP. The estimated overall production of carp in both HSP within 5 months was encouraging, and it is expected that this would increase by 30% over the course of a 12 month production cycle. Households also stocked a portion of small tilapia from IFCAS in the pond to grow them to larger sizes. This indicates that the cage of IFCAS was used as nursery to some extent; an activity which is termed decentralized fish fingerling nursing by Barman and Little (2011). More than 50% of the total fish consumed from the ponds of participating households was tilapia produced from IFCAS, which was available for harvest earlier in the growing season than carp. Moreover, farmers sold tilapia from IFCAS at the end of a four months culture cycle, while carp were still at a relatively small size.

The productivity of vegetables was found to be higher in MSP than HSP, possibly due to higher sunlight exposure to the MSP. However, snake gourd, bitter gourd, bottle gourd and Indian spinach were found to grow well in HSP, at a similar rate to MSP.

The production of vegetables in IFCAS was also found to support the nutrition of farming households, particularly during heavy rainfall in July–September, when no vegetables were grown in the homesteads of participating households, but vegetables were being producing in IFCAS.

Fluctuations in food consumption related to seasonality can cause serious problems for poor households particularly in the case on nutrient rich non-staple foods, resulting in food insecurity. Increasing own on-farm production is recognized as an important strategy by which the poor can cope with vulnerability to the problem of seasonal food insecurity. Production strategies which generate complementarity between enterprises have been suggested for coping with seasonality (Gill, 1991). Both tilapia and vegetable production in IFCAS contributed to the household nutrition during the lean season of fish and vegetable production and resulted in a ‘consumption smoothing’ effect for the farming households. The households participating in IFCAS action research also earned income from selling tilapia of IFCAS more quickly than carp from ponds, during the monsoon when there was no other agricultural produce to sell and earn income. At the rural farm household level, seasonal production variation tends to result in uneven agricultural income. Farm-based diversification such as IFCAS can therefore, contribute to income smoothing, by utilizing labor and generating alternative sources of income in off-peak periods in the traditional farm cycle (Ellis, 2000).

To construct IFCAS, input materials, particularly plastic floating drums and iron bars, were purchased locally and welding services were also taken locally. Due to increasingly widespread electrification in Bangladesh, welding service shops have developed in almost all rural marketplaces (Bose et al., 2013). The rural economy is changing rapidly and many more people are constructing brick built houses with steel doors and windows (Uddin, 2012). These housing accessories are constructed in the growing number of welding shops, which also have potential to provide aquaculture systems engineering for rural areas. This kind of shop could be developed as an enterprise for constructing aquaculture equipment (e.g., IFCAS structures) and could generate further rural non-farm employment. The initial investment in IFCAS during this trial was relatively high. However, even considering depreciation costs, the technology was economically efficient when used in both HSP and MSP, although the rate of return was higher in the latter. This level of economic efficiency is comparable to that of the main agricultural crops, rice, which was found to be 1.3 (Afroz and Islam, 2012), indicating that household investment in IFCAS in shaded ponds may be viable. To improve the productivity of IFCAS in shaded ponds, other species of fish which can survive relatively in poor water quality (e.g., *Anabas testudineus*) could be stocked alone or combination with tilapia and other species under further action research to determine potential productivity of IFCAS in shaded ponds. Finally, it could be argued that a new integrated aquaculture–agriculture technology for resource poor farmers has been developed from participatory action research conducted with farmers, which will not only be useful in shaded ponds but may have applications in Bangladesh for the poor with access a range of water resources, including multi-owner ponds, state-owned ponds, natural water bodies (*beel*), rivers, canals, and water logged areas affected by climate change.

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