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Original Article

Effect of carp species combination on production and economics of stinging catfish, *Heteropneustes fossilis* based polyculture in homestead ponds under drought prone area of Bangladesh

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Abstract
Aquaculture of homestead ponds under drought prone areas is climatically challenged by increased temperature and decreased water level. These ponds are potentials for farming of a short cycle aquaculture species like *Heteropneustes fossilis* with carps but lack of appropriate species combination is the major constraint for promotion of this technique. To address this problem, an experiment was carried out during July to December, 2019 to evaluate the production and economics of *H. fossilis* based polyculture under different carp species combinations in homestead ponds in Tanore of Rajshahi district, Bangladesh. Three different combination of carps were tested under three treatments as T_1: *Labeo rohita* dominant carps (*L. rohita* 50%, *Gibelion catla* 25% and *Hypophthalmichthys molitrix* 25%); T_2: *G. catla* dominant carps (*L. rohita* 25%, *G. catla* 50% and *H. molitrix* 25%); and T_3: *H. molitrix* dominant carps (*L. rohita* 25%, *G. catla* 25% and *H. molitrix* 50%), each with three replications. Stocking densities were 123500 ha^{-1} for of *H. fossilis* was and 988 ha^{-1} for carps. Water quality was monitored monthly and found within acceptable range. T_3 was found significantly ($p < 0.05$) better than other groups in terms of yield and cost benefit ratio.

Keywords: Growth; *Heteropneustes fossilis*; polyculture; species combination; yield

1 | INTRODUCTION

The major problems for aquaculture promotion in drought prone area of Bangladesh are increased temperature, decreased water level and reduced culture period of the ponds (Hossain *et al.* 2009; Talukder *et al.* 2017). Prolonged drought is one of the major threat to the pond fish culture of Bangladesh (Halim *et al.* 2017) which have the potential to directly affect the physiology, behaviour and growth of fish (Abbink *et al.* 2012). Pond aquaculture is differentiated between two main forms of 'homestead pond culture' and 'entrepreneurial pond culture' because the two have considerably different profiles with respect to their origins, species produced, size of operations, intensity of production, amount of capital investment, the socio-economic characteristics of producers, and the level of both primary on-farm employment and secondary employment in associated value chains (Belton *et al.* 2011). The homestead ponds are typically smaller in size ranges from 0.04 ha to 0.1 ha (Jahan *et al.* 2010). The farmers having homestead ponds are often disappointed during harvesting when they find poor growth of native carps cultured with exotic fish species. They are also experienced with the lower production and economic return from current polyculture system. Characteristic soil-water quality with lower fish production is well reported in red soil ponds of drought prone area (e.g. Hossain 2011). This indicates the necessity of developing suitable techniques for homestead ponds under drought prone area in terms of introducing short cycle and high valued aquaculture species with its suitable co-species (e.g. carps), species combination, stocking size and density and feed. Moreover, existing carp polyculture technique is also not suitable for all types of ponds. Importance of stocking overwintered and larger size carps in polyculture ponds under drought prone area is well documented by Hossain *et al.* (2020). Farming of short cycle high valued species with suitable over wintered carp is thus important for effective utilisation of homestead ponds.

The stinging catfish *Heteropneustes fossilis*, locally known as shing, is a potential aquaculture species which has delicious taste, high market value and good acceptance for nutritional and medicinal properties (Chakraborty and Nur 2012). It is considered to be well preferred because of its less bone, less fat and high digestibility in many parts of Indian subcontinent (Khan *et al.* 2003). Earlier it was abundant in closed and open water ecosystems in Bangladesh (e.g. Galib *et al.* 2009; Imteazzaman and Galib 2013; Joadder *et al.* 2015), but due to various natural and anthropological causes, abundance of the fishes in natural waters has been declined (Chaki *et al.* 2014). With the increasing aquaculture development in our country, the seed of this fish currently widely available all over the country especially in Bogura, Mymensingh, Jashore and other districts. The production of *H. fossilis* and walking catfish (*Clarias batrachus*) is reported as 27331 metric tons that contributed 1.44% of the total production of pond aquaculture in Bangladesh (DoF 2018). Culture of *H. fossilis* in monoculture system requires higher investment particularly for expensive artificial feeds which is not affordable to the smallholder farmers however, the use of high-levels of feed inputs has led to deterioration of pond water quality and natural foods in the pond are not utilised properly (Wahab *et al.* 2014). The problems of intensive *H. fossilis* farming are encountered as higher investment, lower survival rates, smaller harvesting sizes and higher feed conversion ratio (FCR) with the increase of stocking densities, deterioration of water quality with higher level of unionised ammonia (0.17 – 0.2 mg L^{-1}) (Rahman *et al.* 2014) due to release of fish faeces and nutrient into water resulting planktonic bloom and natural food organisms that produced in the pond remain unused (Samad *et al.* 2017). High value fish species particularly *H. fossilis* based carp polyculture in homestead ponds can provide higher production and economic benefit to the smallholder farmers compared to the only carp polyculture system. The feeding niches of some carp species in polyculture are reasonably well known, but predicting synergism or competition between *H. fossilis* and carp species remains unknown. A better understanding of intra- and inter-species effects on natural food availability, its exploitation, selection of species combination of carp species, stocking densities of *H. fossilis* and feeding strategies is needed for promotion of this technique. Very little attention has been given on increasing fish production and economic return from stinging catfish based carp polyculture while stocking over wintered carps in homestead pond. Therefore, the present study primarily aimed at evaluating the production and economics of *H. fossilis* based carp polyculture under different species combinations in homestead ponds of drought prone area. The specific objectives of this study were to monitor the water quality and fish growth; to evaluate the production and economics; and finally, to recommend suitable species combination of carps as co-species for *H. fossilis* based polyculture in homestead ponds under drought prone area.

2 | METHODOLOGY

2.1. Location and duration of the study

The experiment was conducted for a period of six months from July to December 2019 in farmer managed homestead ponds (mean area of 0.05 ha and depth of 1.34 ± 0.02 m) located at Jogisho village of Tanore Upazila (sub district) in Rajshahi district, Bangladesh (Figure 1). The ponds were rain fed and exposed to sunlight for most of time of the day.

2.2 Experimental design

A total of three species of carps (*Gibelion catla*, *Hypophthalmichthys molitrix* and *Labeo rohita*) was used as co-species of *H. fossilis*. Randomized completely block design (RCBD) was followed for the present experiment and three different combinations of carps were tested under three treatments as T_1: *L. rohita* dominant carps (*L. rohita* 50%, *G. catla* 25% and *H. molitrix* 25%); T_2: *G. catla* dominant carps (*L. rohita* 25%, *G. catla* 50% and *H. molitrix* 25%); and T_3: *H. molitrix* dominant carps (*L. rohita* 25%, *G. catla* 25% and *H. molitrix* 50%), each with three replications. Treatments were replicated thrice and varied with no significant difference for mean area and depth of the ponds (Tables 1 and 2). Total stocking density of *H. fossilis* (123500 ha^{-1}) and carps (988 ha^{-1}) was same for all the treatments.

The ranges of pond area was 0.049 – 0.052 ha (mean 0.05 ha), 0.047 – 0.054 ha (mean 0.05 ha) and 0.046 – 0.054 ha (mean 0.05 ha) for T_1, T_2 and T_3 respectively while the water depth was 1.3 – 1.36 m, 1.33 – 1.36 m and 1.32 –

1.36 m respectively. However, no significant difference was found in pond water area and water depth among treatments (Table 1).

2.3 Pond management

Aquatic weeds were removed from all the experimental ponds manually. Unwanted fishes and other predatory species were removed from the ponds through repeated netting. Liming was done at the rate of 500 kg ha^{-1} as basal and 50 kg ha^{-1} fortnight^{-1} as periodic dose. Lime treatment in ponds under drought prone area was done after Hossain (2011). No organic manure was used except limited use of inorganic fertilizers (urea: 1.2 kg ha^{-1} day^{-1}; and TSP (triple super phosphate): 1.2 kg ha^{-1} day^{-1}) to enhance the natural feed. Basal fertilisation was done after three days of liming. TSP was wetted overnight and spread over the ponds at following day whereas instant application was done for urea. Both wild (*L. rohita* and *G. catla*) and hatchery (*H. fossilis* and *H. molitrix*) seeds were used for stocking into the ponds under different treatments. Carp seeds were used following overwintering process whereas seeds of *H. fossilis* were shifted from nursery rearing to farmer managed grow out ponds for stocking. Floating pelleted feed (35% protein content) was given to *H. fossilis* at the rate of 7% of the body weight (20% at first fortnight, 12% at second and third fortnights, 7% at fourth and fifth fortnights, 5% at sixth to eighth fortnight, 4% at ninth fortnight, 3% at tenth fortnight and 2% at rest of the fortnights). Twice daily feeding (morning and evening) was followed for all the treatments. Feed ration was adjusted through fortnightly sampling.

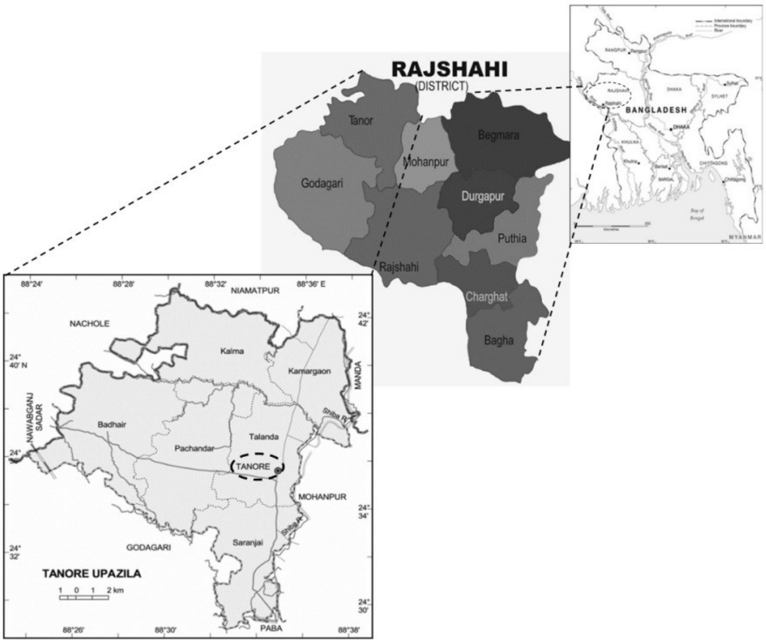

FIGURE 1 Location of the study area indicated with dot circle at Tanore Upazila (sub district) of Rajshahi district, Bangladesh.

TABLE 1 Mean water area and depth of the experimental ponds (*n* = 3).

Pond profile	Treatments			*F* value	*p* value
	T_1	T_2	T_3		
Area (ha)	0.05±0.00	0.05±0.00	0.05±0.00	0.01	0.890
Depth (m)	1.33±0.02	1.33±0.01	1.34±0.01	0.19	0.830

2.4 Monitoring of water quality parameters

Water quality parameters of the experimental ponds were monitored between 0900 and 1000 am in each month. Water temperature (°C) was recorded with the help of a Celsius thermometer at 20 – 30 cm below the water surface. Water transparency (cm) was measured by a Secchi disk. Alkalinity (mg L^{-1}) and ammonia-nitrogen (mg L^{-1}) were determined by the help of a HACH kit (model: FF2, USA). Dissolved oxygen (mg L^{-1}), pH, and total dissolved solids (TDS, mg L^{-1}) were determined by a Multimeter (model: HQ 40D, HACH, USA). Nine small samples of water (20 litre for each sample) were collected from different areas and depths of the each of the experimental ponds and passed through a plankton net (mesh size 55 micron) to count plankton population. Then the collected plankton samples were preserved in 5 % formalin in small plastic bottles to take the sample in the laboratory for further study. Plankton was identified using the key after Ward and Whipple (1959), Prescott (1962) and Bellinger (1992) and their concentration in water (number L^{-1}) was determined by the help of a microscope after Stirling (1985) in laboratory of the Department of Fisheries, University of Rajshahi, Bangladesh.

2.5 Monitoring of fish growth and yield

Fortnightly sampling was done to monitor growth performance of fishes and to adjust the feeding ration. In each sampling date, 10% of the stocked fishes of each species were caught from each pond with the help of a cast net for the study of growth performances of fishes. The examined fishes were then immediately released into the ponds without any harm. Growth, survival and production performances of fishes were analyzed under all the treatments after Brett and Groves (1979) as follows:

Initial weight (g) = Weight of fish at stock
Final weight (g) = weight of fish at harvest
Weight gain = Mean final weight – Mean initial weight

$$SGR\ (\%,\ bwd^{-1}) = \frac{L_n\ final\ weight - L_n\ initial\ weight}{Culture\ period} \times 100$$

$$Survival\ rate\ (\%) = \frac{No.\ of\ fish\ harvested}{No.\ of\ fish\ stocked} \times 100$$

Yield (kg ha^{-1}) = Fish biomass at harvest – Fish biomass at stocking

2.6 Economic analysis

Simple cost-benefit analysis was done to explore the economics. At the end of the study, all the fishes were sold in a local market. The prices of inputs and fish corresponded to the market prices in Rajshahi, Bangladesh in 2020 and were expressed in Bangladesh currency (Taka) as BDT (1 US$ = 83.95 BDT as of January 2020). Data on both fixed and variable costs were recorded to determine the total cost (BDT ha^{-1}). Total return was determined from the market price of fish and was expressed as BDT ha^{-1}. Net benefit (BDT ha^{-1}) was calculated by deducting the total return from total cost. Cost benefit ratio (CBR = Net benefit / total cost) was also determined, after Shang (1990).

2.7 Data analysis

Data on water quality parameters, fish growth and yield, and economics were subjected to one way ANOVA (Analysis of Variance) using computer software SPSS (Statistical Package for Social Science, version 20). The mean values were also compared by Duncan Multiple Range Test (DMRT) after Gomez and Gomez (1984) at 5% level of significance. All data were expressed as mean ± standard error (S.E.).

3 | RESULTS

3.1 Water quality parameters

No significant difference (all $p > 0.05$) was found among the treatments for the mean values of water temperature, transparency, pH, alkalinity, ammonia-nitrogen and total dissolved solids (TDS). Treatments varied significantly ($p < 0.05$) for the mean values of DO, CO_2 and plankton concentration (Table 2). The lowest concentration of plankton was recorded with T_3 by the presence of the highest number of *H. molitrix*. The highest DO and lowest values of CO_2 and ammonia-nitrogen were recorded in treatment T_3. However, water quality parameters under the treatments were found more or less within suitable range for fish culture.

3.2 Fish growth and yield

No significant difference ($p > 0.05$) in weight gain and SGR of carps (*H. molitrix*, *G. catla* and *L. rohita*) was found among the treatments whereas treatment T_3 varied significantly ($p < 0.05$) than others for mean growth (final weight, weight gain and SGR) and yield of *H. fossilis* (Table 3 and Table 4). The highest yield of all species was recorded in treatment T_3 (8791.82 ± 420.07 (kg ha^{-1}) followed by T_2 (7033.72 ± 292.93 kg ha^{-1}) and T_1 (6713.40 ± 369.91 kg ha^{-1}) (Table 3). Comparatively lower growth (in terms of weight gain) of the target species (*H. fossilis*) was recorded with winter period.

TABLE 2 Mean water quality under different treatments during the study.

Water quality	Treatments			*F* value	*p*-value
	T_1	T_2	T_3		
Temperature (°C)	29.87 ± 0.10	29.99 ± 0.22	29.83 ± 0.04	0.29	0.750
Transparency (cm)	25.05 ± 0.11	25.22 ± 0.81	25.33 ± 0.16	0.09	0.920
pH	6.93 ± 0.04	7.01 ± 0.08	7.11 ± 0.16	0.74	0.520
DO (mg L^{-1})	5.33 ± 0.14^{b}	5.62 ± 0.03^{ab}	5.84 ± 0.08^{a}	6.34	**0.030**
Alkalinity (mg L^{-1})	86.39 ± 2.07	86.88 ± 1.88	87.17 ± 0.88	0.05	0.950
CO_2 (mg L^{-1})	1.76 ± 0.03^{a}	1.78 ± 0.10^{a}	1.53 ± 0.03^{b}	4.53	**0.040**
NH_3-N (mg L^{-1})	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.00	1.32	0.330
TDS (mg L^{-1})	280.02 ± 4.53	268.44 ± 4.19	273.94 ± 4.67	1.75	0.250
Phytoplankton (cell L^{-1})	122111 ± 3207.40^{a}	108461 ± 438.99^{b}	97778 ± 1621.83^{c}	34.04	**<0.001**
Zooplankton (cell L^{-1})	88916.7 ± 476.38^{a}	86050 ± 1190.50^{ab}	83405.6 ± 1256.8^{b}	7.07	**0.030**
Total plankton (cell L^{-1})	211027.78 ± 3590^{a}	194511.1 ± 1166.8^{b}	181183.3 ± 2233.5^{c}	34.85	**<0.001**

Figures bearing different letters in a row as superscript differ significantly (p < 0.05)

3.3 Economics

Treatments varied significantly ($p < 0.05$) for the mean values of total cost, net return, net benefit and CBR (Table 5). The highest values of total cost, net return, net benefit and CBR were recorded with treatment T_3.

TABLE 3 Fish growth under different treatments during study from July to December 2019.

Species	Treatment	Initial weight (g)	Final weight (g)	Weight gain (g 6months^{-1})	SGR (%, bwd^{-1})	Survival rate (%)
Heteropneustes fossilis	T_1	1.03 ± 0.01	72.52 ± 2.40^b	71.49 ± 2.41^b	2.36 ± 0.02^b	71.07 ± 2.49
	T_2	1.04 ± 0.01	74.11 ± 2.51^b	73.08 ± 2.52^b	2.37 ± 0.02^b	73.00 ± 2.42
	T_3	1.03 ± 0.00	87.20 ± 2.41^a	86.17 ± 2.40^a	2.39 ± 0.01^a	77.78 ± 1.84
	F value	0.11	10.87	10.84	7.84	2.30
	p value	0.890	**0.010**	**0.010**	**0.020**	0.180
Gibelion catla	T_1	150.84 ± 1.32	861.16 ± 14.07	710.60 ± 14.40	0.97 ± 0.01	71.12 ± 5.09
	T_2	150.95 ± 1.86	845.74 ± 9.70	694.89 ± 9.92	0.96 ± 0.01	70.24 ± 2.76
	T_3	150.78 ± 1.20	878.60 ± 13.30	727.65 ± 13.29	0.99 ± 0.01	73.41 ± 4.32
	F value	0.02	1.71	1.57	0.88	0.15
	p value	0.980	0.260	0.280	0.460	0.860
Hypophthalmichthys molitrix	T_1	212.15 ± 1.05	1201.38 ± 3.69	989.22 ± 2.77	0.96 ± 0.01	73.41 ± 4.26
	T_2	212.67 ± 1.45	1188.82 ± 13.14	976.15 ± 13.00	0.95 ± 0.01	72.73 ± 5.61
	T_3	212.16 ± 1.58	1181.83 ± 18.33	969 ± 1739	0.95 ± 0.01	70.10 ± 1.87
	F value	0.04	0.56	0.62	0.74	0.17
	p value	0.950	0.590	0.560	0.510	0.850
Labeo rohita	T_1	120.70 ± 0.38	741.48 ± 6.83	620.77 ± 6.96	1.00 ± 0.01	67.68 ± 3.42
	T_2	120.61 ± 1.22	750.99 ± 13.49	630.38 ± 13.21	1.02 ± 0.01	69.63 ± 2.30
	T_3	120.57 ± 1.51	764.18 ± 25.22	643.77 ± 26.70	1.03 ± 0.01	71.65 ± 3.24
	F value	0.01	0.45	0.43	0.30	0.43
	p value	0.980	0.650	0.670	0.740	0.660

Figures bearing different letters in a column as superscript differ significantly ($p < 0.05$)

TABLE 4 Fish yield (kg ha^{-1} 6months^{-1}) under different treatments during study.

Species	Treatments			*F* values	*p* values
	T_1	T_2	T_3		
Heteropneustes fossilis	6246.01 ± 370.86^b	6554.64 ± 270.30^b	8260.08 ± 431.07^a	8.90	0.020
Hypophthalmichthys molitrix	165.37 ± 12.17^b	160.89 ± 15.72^b	304.38 ± 11.27^a	30.75	<0.001
Gibelion catla	113.73 ± 7.94^b	218.94 ± 12.63^b	122.18 ± 10.50^a	38.23	<0.001
Labeo rohita	188.27 ± 12.52^b	99.24 ± 2.75^b	105.61 ± 3.03^a	42.78	<0.001
All species	6713.40 ± 369.91^b	7033.72 ± 292.93^b	8791.82 ± 420.07^a	9.41	0.010

Figures bearing different letters in a row as superscript differ significantly ($p < 0.05$)

TABLE 5 Economics of *Heteropneustes fossilis* based carp polyculture under different treatments of co-species combination (calculated for 1 ha pond area) for six months culture period from July to December, 2019.

Items	Treatments			*F* values	*p* values
	T_1	T_2	T_3		
Total cost (BDT ha^{-1})	1024740.00 ± 9865.09^b	1043820.00 ± 7483.74^b	1175380.00 ± 24524.31^a	26.74	<0.001
Total return (BDT ha^{-1})	2374871.61 ± 13279.05^b	2489412.99 ± 9926.92^b	3144540.72 ± 15594^a	9.98	0.010
Net benefit (BDT ha^{-1})	1350131.61 ± 12359.32^b	1445592.99 ± 9595.53^b	1969160.72 ± 13170.94^a	7.96	0.020
CBR	1.32 ± 0.11^b	1.38 ± 0.08^{ab}	1.67 ± 0.07^a	4.15	0.040

Figures bearing different letters in a row as superscript differ significantly ($p < 0.05$)

4 | DISCUSSION

4.1. Water quality parameters

Findings indicated that water quality parameters under the treatments were found more or less within suitable range for fish culture. All metabolic and physiological activities and life processes such as feeding, reproduction, movement and distribution of aquatic organisms are greatly influenced by water temperature (Jhingran 1975). Mean water temperature obtained with the treatments was closer to Boyd (1998) who recommended suitable water temperature of 25 to 32°C for tropical and subtropical species. Boyd (1998) reported transparency between 30 and 45 cm as good for fish culture. Swingle (1967) stated good relationship between pH and fish growth and obtained satisfactory results at pH 6.5 to 9.0. He also reported that water with pH more than 9.5 was unproductive and pH more than 10.0 was lethal for fish. The pH value in alkaline condition in water was supposed to be helpful for proper growth and development of fishes and aquatic organisms (Jhingran 1975). DO content obtained with the treatments was found suitable for fish farming. According to Rahman *et al.* (1992), DO content of a good productive pond should be 5 mg L^{-1} or more. Banerjee (1967) and Bhuiyan (1970) reported 5.0 to 7.0 mg L^{-1} of DO content of water was fair or good in respect of high productivity and water having DO less than 5 mg L^{-1} to be unproductive. Alikunhi (1957) reported that total alkalinity more than 100 mg L^{-1} should be present in high productive water bodies. Comparatively lower values of water pH, transparency and alkalinity obtained with the treatments might be due to the characteristic soil-water quality of the study area (Hossain 2011). Comparatively lower mean values of CO_2 were measured in the pond water under different treatments. Lower CO_2 values are linked with low temperature and lower organic decomposition and higher rate of photosynthesis (Rahman *et al.* 2017). The ammonia-nitrogen was found lower than Rahman *et al.* (2014) who reported ammonia-nitrogen contents from 0.08 to 0.12 mg L^{-1} in the mono culture of *H. fossilis* farming ponds. Boyd (1998) suggested suitable value for ammonia-nitrogen as less than 0.1 mg L^{-1}. The mean TDS values obtained with the treatments seems to be suitable range of fish culture as fish do not appear to be affected by standard concentrations of TDS of 2000 mg L^{-1} (Rana and Jain 2017). The results of the present study also more or less agrees with the findings of Ansari *et al.* (2015) who worked on phytoplankton diversity and water quality assessment of pond in India and Mohammad *et al.* (2015) who studied TDS in water reservoir in India. Comparatively lower plankton concentration recorded with treatment T_3 might be due to the inclusion of higher proportion of silver carp having ability to control plankton bloom, increase DO level and decrease ammonia level in ponds (Milstein *et al.* 2008). Moreover, silver carp can effectively filter phytoplankton, therefore, this biological treatment using silver carp shows a great prospect in pre-treating phytoplankton dominated eutrophic water (Ma *et al.* 2010).

4.2 Fish growth and yield

In the present study lower weight gain of *H. fossilis* was found with starting period which might be due to fry weight bellow the certain point (catch up growth) and rapid weight gain in the later fortnights might be due to higher metabolic rate at suitable temperature and other optimal water quality parameters. The effect of ambient temperature on growth has been studied on various organisms, including many fish species. Generally, increasing the prevailing temperature leads to exponentially increasing growth starting from a certain point of size to up to a certain point after which growth starts to rapidly decrease (Jobling *et al.* 1994). Slow growth due to slow metabolic activity of fish is found in lower water temperature (Boyd 1998).

The results of the experiment indicated that the yield of *H. fossilis* of treatment T_3 was found to be 32.25% and 26.02% higher than treatments T_1 and T_2 respectively. The yield of carps in treatment T_3 was 13.87% and 11.08% higher than treatments T_1 and T_2 respectively. Furthermore, the combined fish yield of treatment T_3 was measured at 30.96% and 25% higher compared to treatment T_1 and T_2 respectively. The highest fish yield with treatment T_3 might be due to the significant role of *H. molitrix* which assisted in maintaining a good pond environment in terms of water quality (effective utilisation of plankton, increased level of DO content and decreased level of harmful gasses) which ultimately enhanced the growth of other fishes. Treatment T_3 varied significantly ($p < 0.05$) for the mean final weight, weight gain and SGR of *H. fossilis*. Samad *et al.* (2017) recorded final weight of *H. fossilis* as 34.50 to 48.10 g using formulated feed having 27 – 31% dietary protein level at 5% of fish body weight. The survival rate of *H. fossilis* recorded in this study was almost closer to the range reported by Chakraborty and Nur (2012) who recorded survival rate of *H. fossilis* between 67.74 and 90.76% in semi-intensive polyculture with *Anabas testudineus*. The highest value of survival rate of *H. fossilis* was recorded with treatment T_3 which received the highest number of *H. molitrix* during stocking. However, such role of *H. molitrix* to maintain good water quality and to improve the fish growth and yield was also strongly supported by Milstein *et al.* (2008) while working on carp polyculture with small indigenous fishes in ponds. The yield obtained in the present study was much higher than the recorded value of Chakraborty and Mirja (2008) who recorded the yield of *H. fossilis* varied from 7276 to 4512 kg ha^{-1} $8months^{-1}$ in monoculture systems at different stocking densities fed on commercial feeds in earthen ponds. Therefore, yield of the present study indicated that suitable appropriate inclusion of *H. molitrix* (*H. molitrix* dominant polyculture) was beneficial for *H. fossilis* based farming in earthen ponds.

4.3 Production economics

Net benefit of treatment T_3 was 36.22% and 45.85% higher than the treatments T_2 and T_1 respectively. Ali *et al.* (2018) recorded net benefits as 636779 to 1517771 BDT ha^{-1} in six months while Saokat *et al.* (2017) estimated the profitability of *H. fossilis* culture in seasonal water bodies in greater northern region of Bangladesh and got the net benefit of BDT 959116.04 ha^{-1} in five months. Moreover, Rahman *et al.* (2014) obtained net benefit of 9277.32 BDT ha^{-1} in six months of *H. fossilis* farming in ponds. The net benefit obtained in this study was higher than the recorded values which might be due to increased production in *H. fossilis* based polyculture compared to monoculture of the species. The results of the present study also suggested that the *H. molitrix* dominated species composition of carps was more profitable for *H. fossilis* based carp polyculture in earthen ponds.

5 | CONCLUSIONS

Overall findings indicated that *H. fossilis* culture in homestead ponds with carps dominated by *H. molitrix* is the best in terms of water quality; fish growth and yield; and economics. This study used only one stocking density of *H. fossilis*. Further study is required for optimising the stocking density of *H. fossilis* in polyculture of carps in homestead ponds under drought prone area.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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SMNN Research design, primary data collection and validation, statistical analysis and draft manuscript (MS) writing; **MAH** assist in research designing, review and validation of data and statistical analysis, review and finalization of the MS; **MMA** assist in statistical analysis and drafting MS preparation; **MHR** review primary data and data analysis; **MAH** review and comments on draft MS.