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Influence of feeding, periphyton and compost application on the performances of striped grey mullet (*Mugil cephalus* L.) fingerlings in fertilized brackishwater ponds

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A B S T R A C T

To evaluate the effects of different management systems on performances of grey mullet (*Mugil cephalus* L.) fingerlings, a 120-day experimental trial was conducted in twelve brackishwater ponds (600 m^2 each). Rearing management systems assessed were: fertilization alone (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC) in triplicate ponds. Soaked mustard cake was used as a fertilizer @ 100 kg ha^{-1} at 15-day intervals in all the treatment ponds. Formulated crumble diet containing 29.7% protein and 4.9% lipid was used as a supplementary feed in FF. Bamboo poles were used as substrates (equivalent to 10% of pond surface area) to facilitate periphyton growth in FP and composted aquatic weed was applied @ 500 kg ha^{-1} in FC at monthly intervals. Ponds were stocked with grey mullet fry (3.36 ± 0.32 g/ 63.70 ± 4.61 mm) at 30,000 number ha^{-1}. The experiment revealed significant differences in most of the water quality parameters among the four treatments. In FP ponds, a significant reduction ($P < 0.05$) in inorganic nitrogen and phosphorous, chlorophyll-a contents, and plankton population was observed. The highest fish growth (28.39 ± 1.94 g) and survival (94.3 ± 4.2%) were recorded in FP followed by in FF, FC and FR ($P < 0.05$). A significantly higher total fish biomass ($P < 0.05$) was obtained in FP (803 ± 29 kg ha^{-1}) followed by in FF (730 ± 37), FC (507 ± 33) and FR (362 ± 22). Condition factor (K) and isometric exponent (b) of length-weight relationship indicated that fingerlings were in better condition with isometric growth ($K = 1.37 \pm 0.13$; $b = 3.01 \pm 0.12$) in FP. Inferior condition with allometric growth was observed in FR, FF and FC systems. These results suggest that periphyton based system can be an appropriate rearing technique for grey mullet fingerling production in brackishwater fertilized ponds as an environment-friendly and sustainable practice.

1. Introduction

Mugil cephalus L. is commonly known as the striped, grey, or black mullet (Nelson et al., 2004), and inhabits tropical and subtropical coastal regions between 42°N and 42°S (Thomson, 1963). It is a commercially important euryhaline and eurythermal species that contributes considerably to the coastal fisheries of many Asia-Pacific, African and European countries (Biswas et al., 2012). Being omnivorous, it feeds on plant detritus and microflora (Moriarty, 1976; Odum, 1970), thus it remains an ecologically important species feeding at the lowest trophic level. Due to these attributes, this species is suitable for monoculture and compatible with other species in polyculture. Although, mariculture and coastal aquaculture production contributed only 15.9% to the world fish production in 2014, a striking share was by relatively high-valued crustaceans and finfishes cultured in brackishwater. Striped/flathead grey mullet as one of the species contributed substantially to the whole share of marine/coastal aquaculture that was 36.2% of the total aquaculture production (FAO, 2016).

In India, grey mullet is a candidate species suitable for culture in brackishwater ponds and has a high consumer preference due to its flesh quality and good flavour. Pond culture of traditional and semi-

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intensive systems mainly depends on seeds available from natural water. In west coast, fry of *M. cephalus* becomes available from the onset of south-west monsoons in November–April (Curian, 1975), whereas in north-east coast, it is available in two phases, January–March and July–August (Biswas et al., 2012). Direct stocking of small fry (15–25 mm) to culture ponds often results in poor production. At initial life stage, this fish grows slowly (Hickling, 1970; Bishara, 1978; De Silva, 1980; Saleh, 2008), therefore, a pre-stocking seed rearing step will be desirable to obtain advanced fingerlings (100–120 mm) that are suitable for grow-out culture.

In different farming environments, in addition to natural food organisms, grey mullet accepts supplementary feed (Curian, 1975; Luzzana et al., 2005). Application of different organic manures and inorganic fertilizers influenced the natural food organisms and had subsequent effects on growth of this fish during farming in pond (Bishara, 1978). Therefore, previously, we tested combination of fertilization with feeding system for rearing of grey mullet fry and observed that fish performance was better in this system than in feeding or fertilization alone at a stocking density of 15,000 number ha^{-1} (Biswas et al., 2012). However, in the context of increasing price of fish feed, eutrofication due to organic load in fish ponds and sustainability issue, it is high time to explore the method that harnesses natural productivity. For this purpose, organic input based systems would be appropriate eco-friendly methods. In this regard, composted aquatic weed as low cost farm-made organic manure could be an effective alternative as it is often used in traditional brackishwater aquaculture ponds in India. Another environment friendly and unconventional natural feed supplementation system, production and utilization of periphyton are a recent concept in aquaculture. Employing various submerged substrates, growth and use of periphyton which is a complex of microalgae, bacteria and detritus to convert into fish biomass have been extensively evaluated in freshwater aquaculture, particularly in carps (Wahab et al., 1999; Keshavanath et al., 2001; Azim et al., 2002), tilapia (Asaduzzaman et al., 2009), catfish (Amisah et al., 2008) and giant freshwater prawn (Asaduzzaman et al., 2008). Similarly, periphyton utilization was also tested for mullets, for instances, *M. cephalus* performed better in inland saline groundwater ponds (Jana et al., 2004) and *Liza aurata* in marine cages (Richard et al., 2010). In addition to the contribution of periphyton to fish biomass, the submerged substrates added to aquatic system improve water quality by trapping suspended solids and thereby enhance nitrification (Ramesh et al., 1999; Thompson et al., 2002). Although various works demonstrated the benefits of periphyton or fertilization system in fish fingerling rearing, there is a dearth of information on the comparative performance of periphyton system with other alternative cheap organic input based systems. In this context, the present study aims at comparing growth, survival and organism condition indicators along with hydrobiological parameters and economic returns for different pond management systems (fertilization alone, combined fertilization-feeding, fertilization-periphyton and fertilization-organic compost application) during grey mullet fingerling production in brackishwater.

2. Materials and methods

2.1. Experimental site and design

The experiment was conducted for a period of 120 days in the brackishwater farm of Kakdwip Research Centre (KRC) of ICAR-Central Institute of Brackishwater Aquaculture (CIBA), Kakdwip, South 24 Parganas, West Bengal, India.

Twelve rectangular earthen ponds (600 m^2 each) were used. Four rearing systems tested in this experiment formed four treatments: fertilization alone (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC). Each treatment had three replicate ponds which were randomly assigned between treatments. Stocking density of grey mullet advanced fry (3.36 ± 0.32 g/63.70 ± 4.61 mm) was 30,000 number ha^{-1}. This stocking density was derived based on our previous study (Biswas et al., 2012) that suggested use of higher density than 15,000 number ha^{-1}, and consequent experiments conducted at our farm (unpublished).

2.2. Pre-stocking pond management

The ponds were sun-dried and then agricultural lime ($CaCO_3$) was applied to each pond bottom at 300 kg ha^{-1} (day 1). After 3 days of lime application, ponds were filled with filtered brackishwater drawn through tide from the nearby Creek of Muriganga River to a depth of 50 cm. On day 5, all the ponds were fertilized with mustard cake (4.84% total nitrogen, N; 2.06% total phosphorus, P; 1.32% total potassium, K on dry weight basis), urea (46% available N) and single super phosphate (16% available P) at 200, 20 and 20 kg ha^{-1}, respectively. Then the ponds were left for 5 days to allow growth of natural fish food organisms and water level was finally increased to 150 cm on day 10. On day 11, semi-dried bamboo poles (2 m long; 10 cm dia) were erected vertically on the pond bottom in FP treatment ponds to act as substrates for periphyton growth. Submerged surface area of bamboo poles was calculated and accordingly, 2650 number ha^{-1} were used to provide an added surface area equivalent to 10% of pond surface. Composted aquatic weed (2.27% N, 0.16% P and 2.92% K) was applied at 500 kg ha^{-1} to all the replicate ponds of FC treatment in five nylon net bags placed at four corners and middle of ponds. The net bags were tied to vertically driven bamboo poles to allow leaching and sustained release of nutrients. For preparation of compost, aquatic weeds (*Chara* sp. and *Enteromorpha* sp.) were collected from KRC farm and composted for a month following the Indore method (Howard and Wad, 1931) with a slight modification. An earthen pit (L × B × D: 2 × 1.5 × 1.5 m) was filled with collected raw weeds in layers of 25–30 cm. Between two layers, previously prepared compost mixture was applied at 5 cm thickness. A final layer of weed was kept on top. The pit was covered with moist gunny bags and water was sprinkled at 4-day intervals. At an interval of 10 days, compost materials were turned upside down to ensure proper decomposition. On day 20, ponds were stocked with *M. cephalus* advanced fry pre-acclimated to farm conditions for 30 days in a pre-nursery pond.

2.3. Post-stocking pond management

After stocking, all the ponds under different treatments were fertilized fortnightly with mustard cake at 100 kg ha^{-1}. This was done to eliminate the effect of fertilization from other treatments and enable FR to act as the control. Mustard cake was soaked overnight and diluted with pond water prior to application. Agricultural lime at 100 kg ha^{-1} was applied one day before mustard cake application throughout the rearing period to keep pH level within desirable range. In FF treatment ponds, formulated crumble diet (1 mm) was used as a supplementary feed provided in feeding trays. Daily ration was distributed in two equal meals in the morning (0900 h) and afternoon (1500 h). Proximate composition of feed determined (AOAC, 1995) as % dry matter was as follows: organic matter (84.5), crude protein (CP: 29.7), lipid (L: 4.9), crude fibre (CF: 9.2), acid insoluble ash (4.1) and nitrogen free extract (45.3). Feed quantity was adjusted at 15-day intervals based on an estimated biomass from random samples of 15% stocked fish. Feeding rate was kept at 10–4% of the estimated fish biomass at a decreasing order. In FC treatment ponds, bags containing composted aquatic weed were replaced at 30-day intervals. Pond water depth was maintained at 150 cm after compensating seepage and evaporation loss of water during high tide at monthly intervals.

2.4. Determination of water quality parameters

At 15-day intervals, water temperature, salinity, pH, dissolved oxygen (DO), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), total

Table 1
Effects of fertilization (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC) systems on water quality parameters in grey mullet fingerling rearing ponds.

Water parameter	FR	FF	FP	FC
Temperature (°C)	29.9 ± 1.7	29.9 ± 1.7	29.7 ± 1.9	29.8 ± 1.7
pH	8.34 ± 0.23	8.26 ± 0.25	8.38 ± 0.31	8.31 ± 0.27
DO (mg L^{-1})	5.89 ± 0.42^{b}	5.86 ± 0.52^{b}	6.06 ± 0.52^{c}	5.47 ± 0.71^{a}
Salinity (g L^{-1})	11.87 ± 5.34	11.74 ± 5.32	11.89 ± 5.19	12.17 ± 5.24
NO_2-N (μg L^{-1})	43.75 ± 3.83^{b}	54.61 ± 10.62^{d}	36.71 ± 6.63^{a}	48.09 ± 6.07^{c}
NO_3-N (μg L^{-1})	194.12 ± 15.41^{ab}	279.46 ± 11.14^{c}	175.77 ± 8.94^{a}	227.91 ± 30.72^{b}
TAN (μg L^{-1})	216.16 ± 44.61^{b}	244.19 ± 52.91^{bc}	174.89 ± 36.27^{a}	253.17 ± 66.52^{c}
PO_4-P (μg L^{-1})	132.67 ± 16.43^{b}	169.11 ± 8.98^{d}	107.62 ± 12.74^{a}	145.33 ± 15.39^{c}
GPP (mg C m^{-3} h^{-1})	233.31 ± 14.77^{b}	296.61 ± 19.54^{d}	192.42 ± 12.90^{a}	257.82 ± 22.87^{c}
NPP (mg C m^{-3} h^{-1})	176.86 ± 11.25^{b}	193.66 ± 15.39^{d}	111.34 ± 8.3^{a}	184.27 ± 16.08^{c}

Means bearing different superscripts indicate significant differences in a row ($P < 0.05$); DO, dissolved oxygen; TAN, total ammonia-nitrogen; GPP, gross primary productivity; NPP, net primary productivity; Values are expressed as mean ± S.E. of three replicate ponds.

ammonia-nitrogen (TAN), phosphate-phosphorus (PO_4-P), gross primary productivity (GPP), net primary productivity (NPP) and chlorophyll-a were measured from pond water samples collected between 09:00 and 10:00 h following standard methods (APHA, 1998), and salinity was recorded using a refractometer (ATAGO, Japan). Plankton samples were collected monthly by filtering 50 L of water through bolting silk plankton net (mesh size 64 μm). Plankton concentrates were immediately preserved in 5% buffered formalin for further qualitative and quantitative analysis following direct census method (Jhingran et al., 1969) using a Sedgewick-Rafter counting cell.

2.5. Estimation of chlorophyll-a content of water and periphyton biomass from substrate

Estimation of chlorophyll-a (Chl-a) pigment in water and periphyton in FP ponds was carried out at fortnightly intervals as per standard methods (APHA, 1998). The periphyton biomass in the form of dry mater (DM) and chlorophyll-a content were determined. From each pond, three bamboo poles were randomly selected, and $2 \times 2\ cm^2$ samples of periphyton were collected by scrapping (Anand et al., 2013). After sample collection, the bamboo poles were replaced in their original positions, marked and excluded from subsequent samplings. The scrapped material from each bamboo pole was then transferred into a pre-weighed and labeled crucible, dried at 105 °C and kept in a desiccator until weighed.

2.6. Fish performance evaluation

Gravimetric data of fish were collected fortnightly throughout the experimental period. Total length (TL, mm) was recorded with a slide caliper, while body weight (W, g) was measured using a digital electronic balance.

Daily weight gain (DWG) is a function of weight and time and was estimated for each replicate pond with the formula:

$$DWG = \frac{W_f - W_i}{t}$$

where W_f and W_i are the average final and initial weight in time t.

Specific growth rate (SGR) was calculated using the conventional equation:

$$SGR = \frac{\ln W_f - \ln W_i}{t} \times 100$$

where W_f and W_i are the average final and initial weight in time t.

The mathematical relationship between length and weight was calculated using the conventional formula (Pauly, 1984):

$$W = a.\ TL^b$$

where W is fish weight (g), TL is total length (mm), a is the proportionality constant and b is the isometric exponent. The parameters a and b were estimated by non-linear regression analysis.

Fulton's condition equation was used to find out the condition factor (Chow and Sandifer, 1991):

$$K = \frac{\overline{w}}{(\overline{TL})^3} \times 10^5$$

where K is the condition factor, $\overline{w}$ is the average weight (g) and $\overline{TL}$ is the average total length (mm).

Final average body weight (ABW, g) and length (AVL, mm), survival (%) and total biomass produced (kg) were estimated after harvest by drag netting and dewatering the ponds finally.

2.7. Economic analysis

An economic analysis to compare the treatments was performed with estimation of the net return and benefit-cost ratio (BCR) as per the methods described previously (Biswas et al., 2012).

2.8. Statistical analysis

Differences in final length, weight, DWG, SGR, survival, isometric exponent (b) of LWR and economic returns among treatments were determined by one-way ANOVA with the General Linear Model procedure using SPSS for Windows v.17.0 programme (SPSS Inc., Chicago, IL, USA). Duncan's Multiple Range Test (Duncan, 1955) was used for comparison of treatments. Statistical significance of b was analyzed to evaluate the LWR in each treatment using t-test (Snedecor and Cochran, 1967). All data are expressed as mean ± standard error (S.E.).

3. Results

3.1. Water quality parameters

Water quality parameters of the experimental ponds are presented in Table 1. All the measured parameters differed significantly ($P < 0.05$) between the rearing systems except temperature, pH and salinity. Temperature varied between 32.3 and 26.4 °C, and salinity ranged between 18.3 and 7.17 ppt throughout the study period. The highest value of temperature was recorded in August and the lowest was in November. Although, pH level was higher in FP (8.38 ± 0.31), it was not different ($P > 0.05$) from that of other treatments. Integration of fertilization with feeding (FF) and compost application (FC) significantly ($P < 0.05$) reduced dissolved oxygen (DO) concentration, whereas a significant increase ($P < 0.05$) was observed in fertilization-periphyton system (FP). Mean value of NO_2-N was significantly the lowest ($P > 0.05$) in FP (36.71 ± 6.63 μg L^{-1}) followed by that in FR (43.75 ± 3.83 μg L^{-1}), FC (48.09 ± 6.07 μg L^{-1}) and FF (54.61 ± 10.62 μg L^{-1}). NO_3-N remained significantly lower

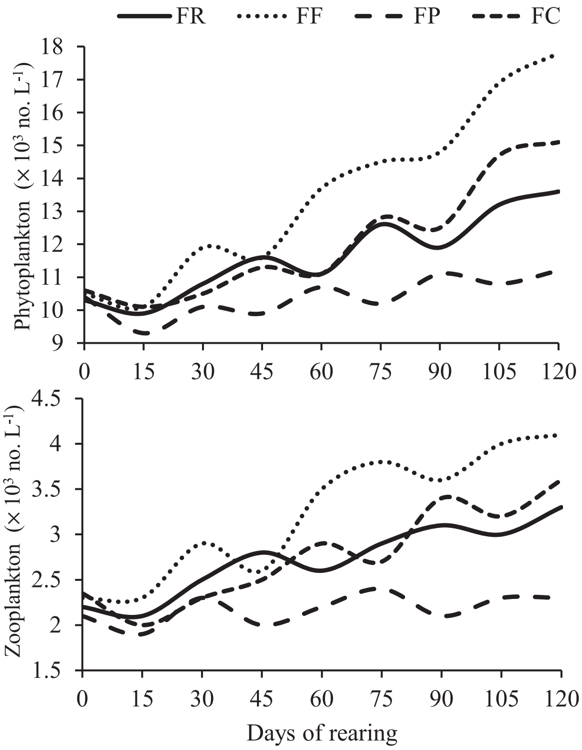

Fig. 1. Plankton counts in pond water under fertilization (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC) systems during grey mullet fingerling rearing in brackishwater ponds.

($P < 0.05$) in FP (175.77 ± 8.94 μg L^{-1}) and the highest value was observed in FF (279.46 ± 11.14 μg L^{-1}), however, values in FC and FR were not significantly different ($P > 0.05$). Similarly, the lowest value of TAN was observed in FP (174.89 ± 36.27 μg L^{-1}) which was significantly different ($P < 0.05$) from that of other treatments and the highest mean value was recorded in FC (253.17 ± 66.52 μg L^{-1}). PO_4-P concentration was reduced by 18.88% in FP and increased by 27.46 and 9.54% in FF and FC, respectively compared to that of FR. The lowest values of GPP and NPP were recorded in FP (192.42 ± 12.90 and 111.34 ± 8.3 mg C m^{-3} h^{-1}) and significantly higher mean values were recorded in all other treatments with the highest values in FF (296.61 ± 19.54 and 193.66 ± 15.39 mg C m^{-3} h^{-1}).

3.2. Planktons, chlorophyll-a content of water and periphyton biomass

Combination of fertilization with feeding or periphyton had significant effects on plankton densities (Fig. 1) and chlorophyll-a (Chl-a) content (Fig. 2) in pond water with higher values in FF and lower values in FP ponds. Plankton densities (phytoplankton and zooplankton) and Chl-a content varied significantly over the experimental period, and the mean values showed an increasing trend till the end of rearing period except in FP where mean values were almost steady with slightly decreasing trend at the end.

Periphyton biomass in the form of dry matter (DM) and Chl-a content per unit surface area over the time period in FP ponds are presented in Fig. 3. DM and Chl-a were found to increase steadily over the period till 75 days of rearing followed by a drop. Afterwards, those remained almost steady till 120 days with insignificant fluctuations. Mean values of DM and Chl-a were 15.06 ± 2.78 mg cm^{-2} and 30.25 ± 3.90 μg cm^{-2}, respectively. About 26 genera of phytoplankton belonging to Bacillariophyceae (11 genera), Chlorophyceae (8), Cyanophyceae (5) and Euglenophyceae (2) and zooplankton belonging to protozoa, annelida and crustacea were identified as periphytic communities grown on the substrate.

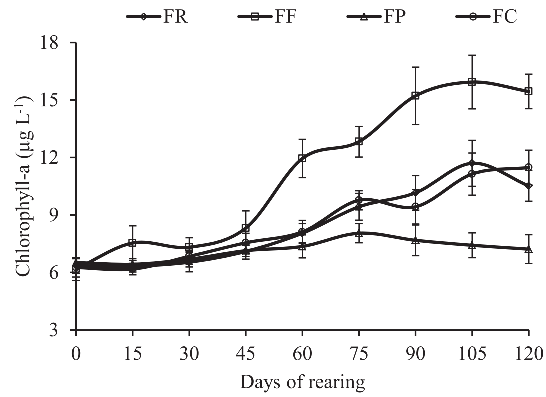

Fig. 2. Chlorophyll-a concentration in pond water under fertilization (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC) systems during grey mullet fingerling rearing in brackishwater ponds.

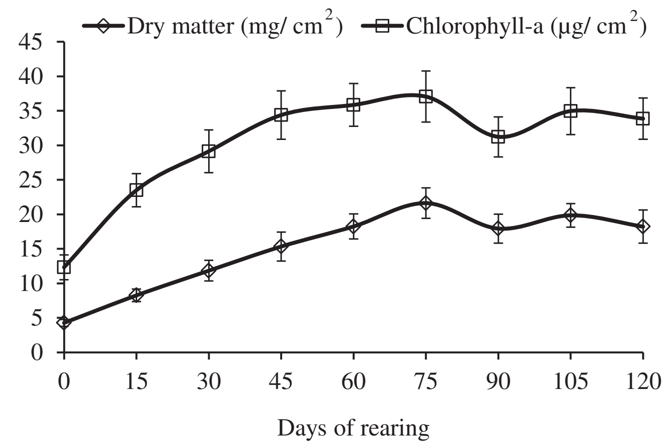

Fig. 3. Chlorophyll-a concentration and dry matter per unit surface area of periphyton in fertilization-periphyton (FP) treatment during grey mullet fingerling rearing in brackishwater ponds.

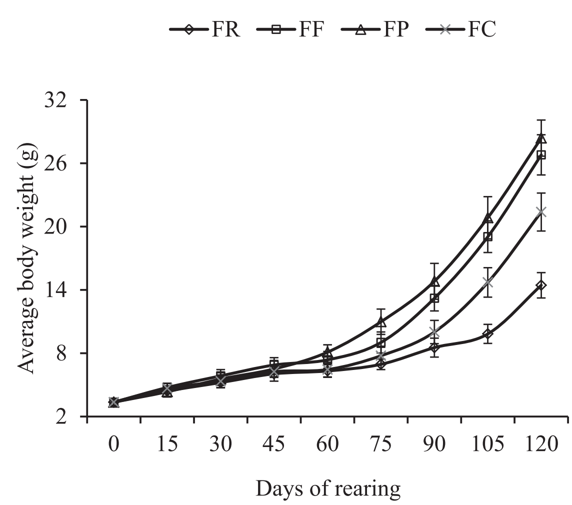

Fig. 4. Body weight increment of grey mullet under fertilization (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC) systems during brackishwater pond rearing.

3.3. Fish growth and performance parameters

Growth increment of grey mullet fingerlings over the time period is presented in Fig. 4. All the growth parameters were significantly ($P < 0.05$) higher in FP compared to that of other treatments

Table 2
Comparison of grey mullet performance parameters in fertilization (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC) systems.

Parameter	FR	FF	FP	FC
Final weight (g)	14.44 ± 1.21[a]	26.80 ± 1.98[c]	28.39 ± 1.94[d]	21.38 ± 1.85[b]
Final total length (mm)	104.43 ± 4.22[a]	119.53 ± 3.86[bc]	123.59 ± 3.22[c]	115.03 ± 5.01[b]
DWG ($g\ d^{-1}$)	0.09 ± 0.02[a]	0.19 ± 0.06[c]	0.21 ± 0.03[d]	0.15 ± 0.05[b]
SGR ($\%\ d^{-1}$)	1.22 ± 0.30[a]	1.73 ± 0.36[c]	1.78 ± 0.39[c]	1.54 ± 0.32[b]
Survival (%)	83.6 ± 7.1[b]	90.8 ± 5.7[c]	94.3 ± 4.2[d]	79.1 ± 6.5[a]
Total biomass ($kg\ ha^{-1}$)	362 ± 22[a]	730 ± 37[c]	803 ± 29[d]	507 ± 32[b]
Condition factor (K)	1.16 ± 0.14[a]	1.26 ± 0.09[b]	1.37 ± 0.13[c]	1.24 ± 0.10[b]

Means bearing different superscripts indicate significant differences in a row ($P < 0.05$); DWG, daily weight gain; SGR, specific growth rate; Values are expressed as mean ± S.E. of three replicate ponds.

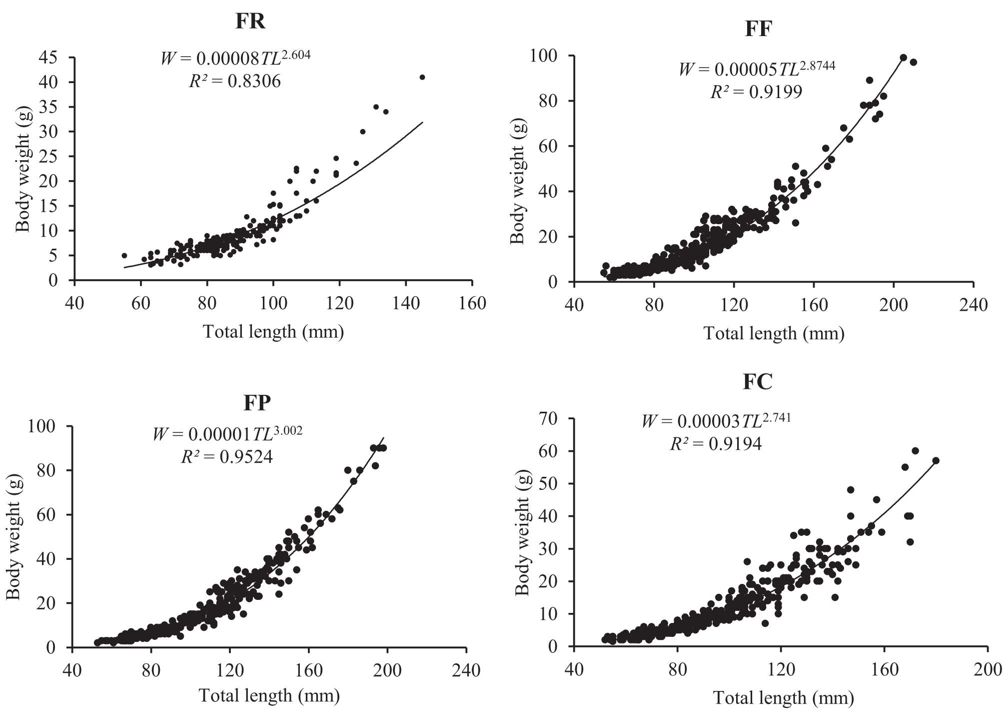

Fig. 5. Length-weight relationship of grey mullet under fertilization (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC) systems during brackishwater pond rearing.

Table 3
Comparison of economic parameters among fertilization (FR), combined fertilization-feeding (FF), fertilization-periphyton (FP) and fertilization-compost application (FC) systems for grey mullet fingerling production. Calculation was for 1 ha water area and 120 days experimental duration. Currency mentioned is Indian Rupee (100 INR = 1.55US$).

Items	Quantity	Price rate	FR	FF	FP	FC
Operational cost (OC)						
Grey mullet fry	30,000 no.	10 fry^{-1}	300,000	300,000	300,000	300,000
Organic manure	800 kg	25 kg^{-1}	20,000	20,000	20,000	20,000
Feed	1100 kg	40 kg^{-1}	–	44,000	–	–
Bamboo poles as substrate	600 no.	40 2 m $bamboo^{-1}$	–	–	24,000	–
Aquatic weed collection	–	–	–	–	–	10,000
Lime	1000 kg	8 kg^{-1}	8000	8000	8000	8000
Man power	200, 250, 300 and 300 man-days in FR, FF, FP and FC, respectively	250 $man\text{-}day^{-1}$	50,000	62,500	75,000	75,000
Sub total			378,000	434,500	427,000	413,000
Interest on OC (4 months)		12% annually	15,120	17,380	17,080	16,520
Total OC			393,120	451,880	444,080	429,520
Economic return						
Fingerling sale	27240, 27240, 28290 and 23730 no. in FR, FF, FP and FC, respectively	20, 28, 30 and 25 $fingerling^{-1}$ from FR, FF, FP and FC, respectively	501600[a]	762720[b]	848700[c]	593250[a]
Net return			108480[a]	310840[b]	404620[c]	163730[a]
Benefit-cost ratio (BCR)			1.28[a]	1.69[b]	1.91[c]	1.38[a]

Means with different superscripts differ significantly in a row ($P < 0.05$); values are means of three replicates.

(Table 2). Mean growth parameters, survival and total biomass at harvest differed significantly ($P < 0.05$) among treatments. Highest DWG was found in FP and its values followed the order of FP > FF > FC > FR. Although, SGR showed similar trend, it did not differed significantly ($P > 0.05$) between FP and FF. When compared to FR, combination of fertilization with feeding (FF) and periphyton (FP) increased survival by 8.6 and 12.8%, respectively, but survival was reduced by 5.4% when combined with compost application (FC). Although, the lowest survival (79.1 ± 6.5%) was in FC, it produced significantly higher biomass due to much higher final body weight compared to FR. However, the highest biomass was produced by FP (803 ± 29 kg ha^{-1}) and the lowest was in FR (362 ± 22 kg ha^{-1}). Fish in FP had the highest Fulton's condition factor (K) level (1.37 ± 0.13) which was significantly different from that of other treatments ($P < 0.05$) following the trend similar to growth parameters (Table 2). Similarly, exponential value (b) of length-weight relationship (LWR) differed significantly ($P < 0.05$) among treatments and followed the order of FP > FF > FC > FR (Fig. 5). According to the slope value ($b = 3.01$), growth in FP treatment was isometric, and, based on t, it was not different from 3 ($t = 0.96$; $P > 0.05$). The slopes for the FF, FC and FR treatments differed from 3 ($t = 3.85$, $t = 9.25$ and $t = 12.55$, respectively; $P < 0.05$) and therefore, indicated allometric growth.

3.4. Comparison of economic returns

Pond management system in FP significantly ($P < 0.05$) increased the gross return, net return and BCR (Table 3). However, there were no significant differences in gross return, net return and BCR between FR and FC systems.

4. Discussion

Water quality parameters remained stable throughout the experimental period and were within the optimum ranges for brackishwater shrimp and finfish culture (Ali et al., 1999; Bhowmik et al., 1992; Chakraborti et al., 2002; Jana et al., 2004). Water temperature and salinity may pose a significantly greater effect on growth in various cultivable aquatic organisms (O'Brien, 1994; Tsuzuki et al., 2000). However, in our experiment, there was no difference in temperature, pH and salinity indicating that differences in weight gain can be attributed to the varied pond rearing systems only. Fortnightly application of lime contributed to desirable water quality. The observed slight higher pH in ponds provided with periphyton substrate may be attributed to less or no nutrient wastage and maintenance of aerobic condition in presence of autotrophic organisms (Azim and Little, 2006). The treatment, where bamboo substrate was provided for periphyton growth (FP) was more effective in removal of toxic nitrogen metabolites compared to other treatments. In the substrate-based system, in addition to phytoplankton, periphytic algae developed over the substrate utilized the available nitrate and phosphate compounds, and reduced their levels in water column (Ramesh et al., 1999; Ballester et al., 2007). Inorganic nitrogenous (NO_2-N, NO_3-N and TAN) and phosphate-phosphorus concentrations were higher in FR, FF and FC treatment ponds compared to that of FP ponds, but these values were below the desirable limits of 0.25, 0.5, 1.0 and 1.0 mg L^{-1}, respectively (Chakraborti et al., 2002). These higher values in FR, FF and FC were due to the effect of mustard cake, feed and compost application. Again, use of nutrients by phytoplankton perhaps caused this situation that resulted in chemical gradients which in turn accelerate quick supply from the soil, thus increasing nutrient concentration in the water (Boyd, 1979). GPP and NPP showed similar trend and those had a significant ($P < 0.05$) positive correlation with NO_3-N and PO_4-P. Similar observations were reported by Garg et al. (2006) in inland saline groundwater ponds applied with different doses of fertilization.

In the present study, both phytoplankton and zooplankton populations were significantly higher in FF, FC and FR ponds compared to that of FP ponds. Chlorophyll-a contents also coincided with the phytoplankton population. This was mainly because of periodic pond fertilization that helped in continuous propagation of phytoplankton population (Mischke and Zimba, 2004). Further increase in plankton population was observed while combined with feeding and compost application. Lower but steady plankton counts throughout the experimental period in FP were due to competition for resources between phytoplankton and periphyton assemblages (Havens et al., 1996). Thus, results of this experiment suggest that use of bamboo substrate improved water quality by nitrification process involving microbial and periphytic algal communities (Anand et al., 2013).

Periphyton dry matter and chlorophyll-a content per unit surface area in the present study showed average values of 14.95 ± 3.23 mg cm^{-2} and 29.47 ± 4.85 μg cm^{-2}, respectively in FP treatment ponds. Our results represent much higher values compared to the periphyton dry matter levels reported as 9.9 mg cm^{-2} in marine system (Richard et al., 2010), 0.8–1.4 mg cm^{-2} in inland saline groundwater ponds (Jana et al., 2004) and 2.8–14.4 mg cm^{-2} in tank experiments at different carbon-nitrogen ratios (Anand et al., 2013). In general, the quantity and quality of periphyton developed on substrates vary according to the type of ecosystem, substrate and nutrient availability (Richard et al., 2009). In the present study, periphyton dry matter and chlorophyll-a contents increased steadily up to 75 days followed by an almost steady state till the end. Increasing amount of periphyton biomass indicated low grazing pressure on the periphyton by overall low biomass of fish initially and steady or low periphyton biomass was resulted from increasing or appropriate grazing pressure after 75 days by growing fish with higher biomass at selected stocking density. This suggests further investigation on the manipulation of fertilization/feeding rate and stocking density of cultured animals (Asaduzzaman et al., 2008). Periphytic algae grown on bamboo substrates comprised of diatoms, filamentous green and blue green algae, and zooplankton groups like crustaceans, nematodes and ciliate protozoans. Khatoon et al. (2009) reported similar observations in marine shrimp ponds where diatoms were the dominant periphyton community.

Growth parameters and survival in grey mullet fingerlings were affected by fertilization alone, and combination of fertilization with feeding, periphyton substrate and compost application. However, the combined fertilization-periphyton system produced bigger fingerlings with better survival. This may be attributed to the fact that either combination of feeding or compost with fertilization and fertilization alone could not meet up the biological need of growing fish, whereas combined fertilization-periphyton system catered the requirement more efficiently. The growth of *M. cephalus* recorded in fertilization-periphyton system in this study was higher than the observations of Bishara (1978) who reported that in 180 days, fish reached 25 g in superphosphate fertilization, 27 g in superphosphate + ammonium nitrate fertilization, 12 g in feeding with powdered blood + ordinary flour, 18 g in feeding with ricebran + cotton seed cake, 12 g in rice bran feeding, 13 g in organic manure fertilization and 11 g in untreated and unfed ponds stocked at 10000 number ha^{-1}. Similarly, Shofiquzzoha et al. (2001) demonstrated that *M. cephalus* attained 7.30–10.91 g from the initial size of 1.22 g in an 85-day polyculture with *Liza parsia* and *Penaeus monodon*. However, this fish attained higher growth of 61–91 g in 90 days under different salinities (Barman et al., 2005) and 121–264 g in 100 days under various doses of cow dung manuring (Garg et al., 2006) in inland saline groundwater. In the present experiment, SGR of grey mullet was lower compared with the report of Jana et al. (2004), who observed SGR of 2.5 ± 0.1 and 2.2 ± 0.1% d^{-1} in ponds with periphyton and without periphyton, respectively. Higher SGR value of 3.12–4.70% d^{-1} was recorded in this fish reared under various salinity levels of inland groundwater (Barman et al., 2005). In this experiment, the highest survival (94.3 ± 4.2%) in combined fertilization-periphyton system suggested its suitability for grey mullet fingerling rearing.

The recorded survival of grey mullet in different pond management systems was higher compared with 43–63% in a monoculture of 200-day duration (James et al., 1985) and 56.67–64.67% in a polyculture with tiger shrimp for 195 days of rearing (Shofiquzzoha et al., 2001). Higher harvested ABW, DWG, SGR and lower survival were observed in the same environment at a lower stocking density (7500 number ha^{-1}) and longer culture duration (150 days) in fertilization, feeding and combined fertilization-feeding systems (Biswas et al., 2012). The highest total harvested biomass of grey mullet fingerlings was recorded in the fertilization-periphyton system. This indicated that natural food in the form of periphyton, plankton and benthos contributed significantly to higher fish biomass in fingerling rearing phase. In natural habitat, grey mullet feeds on all available food, microalgae, benthic invertebrates, and decaying detritus (Truslé, 1981; Lupatsch et al., 2003; Odum, 1970). Our observations corroborate the findings of Richard et al. (2010), who reported that survival, growth and production of mullets were better in periphyton-based systems than in fed systems. Pruginin et al. (1975) observed that natural food in marine ponds was more appropriate compared to only pellet feed feeding for rearing of mullet. Our findings were in the similar line.

Examination of the *K* value in FP indicated that grey mullet exhibited more healthy and robust condition showing good compatibility with the environment. Condition factor is used to compare the 'condition', 'fatness' or 'well being' of fish and it also indicates that heavier fish of a given length are in better condition (Biswas et al., 2011).

Isometric exponent (*b*) value (3.01) in FP indicated that fish had a good LWR and were, therefore, in good condition compared to other treatments. Growth is considered isometric when the parameter *b* is equal to 3 and allometric when it is < or > 3 (Enin, 1994). More specifically, growth is to be positive allometric when organism weight increases more than length ($b > 3$), and negative allometric when length increases more than weight ($b < 3$) (Wootton, 1992). Jana et al. (2004) reported similar results in inland saline groundwater. Our observation indicates superiority of periphyton supported system to other fingerling rearing systems of *M. cephalus*.

From economic analysis, it is evident that fertilization-periphyton system of pond management significantly outperformed other three systems. In our previous study, combined fertilization-feeding system was better compared to fertilization or feeding alone (Biswas et al., 2012). Accounting all the input costs in the four systems, a significant 30% higher net return margin was obtained in fertilization-periphyton system compared to the fertilization-feeding system.

5. Conclusion

The pond trial on grey mullet fingerling rearing under fertilization alone, and feeding, periphyton and compost application combined with fertilization revealed better performances in the fertilization-periphyton system. Bamboo-based substrate facilitated maintenance of better water quality by reducing toxic compounds like TAN and NO_2-N, and improved growth performance and survival of grey mullet fingerlings. Substrate favoured growth of periphytic algal community that served as the natural food. This study infers that combined fertilization-periphyton system with a stocking density of 30,000 fry ha^{-1} would be appropriate for production of striped grey mullet fingerlings in brackishwater pond. There is a scope for refinement of this practice by evaluating appropriate surface area of substrate to support the growing fish biomass. An understanding on the quantitative and qualitative utilization of periphytic algae by *M. cephalus* during different life stages, and standardization of stocking density for optimum utilization of the developed periphyton biomass would help in further refining such system.

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