J. Bangladesh Acad. Sci. 47(1); 43-52: June 2023 DOI: https://doi.org/10.3329/jbas.v47i1.66683

Journal of Bangladesh Academy of Sciences

Journal homepage: http://www.bas.org.bd/publications/jbas.html

Research Article

Commercial Nile tilapia *Oreochromis niloticus* production in net cages at the River Dakatia, Chandpur, Bangladesh

Md. Robiul Awal Hossain[1], Md. Eilious Hosain, Anika Tabassum and Md. Niamul Naser*

Department of Zoology, Faculty of Biological Sciences, University of Dhaka, Dhaka, Bangladesh

ARTICLE INFO

Article History

Received: 20 November 2022
Revised: 21 May 2023
Accepted: 11 June 2023

Keywords: GIFT, Growth, river ecosystem, Net-cage farming, Mono-sex tilapia, *Oreochromis niloticus*, River Dakatia, Bangladesh

ABSTRACT

This study examined the intensification of mono-sex Nile tilapia *Oreochromis niloticus* aquaculture in riverine net cages installed at the River Dakatia, Roghunathpur, Chandpur. This study performed 120-day cage grow-out trials with densities of 50, 75, and 100 tilapia m^{-3} under three replications with an average initial weight of 28.92±8.37 g per juvenile fish. The monthly water quality parameters (temperature, pH, dissolved oxygen, total alkalinity and hardness, ammonia-N and Nitrite-N) in the cage installation water area of the River Dakatia were found to be suitable for tilapia cage culture. The monthly average weight gain was significantly (p < 0.05) higher in 50 tilapia m^{-3} stocking density than in the other two stocking densities tested. The mean final weight and specific growth rate were significantly (p < 0.05) higher in 50 tilapia m^{-3} stocking density than the other two stocking densities. Significantly (p < 0.05) higher survival (97.92%) was found in the 50 tilapia m^{-3} stocking density group and followed by 86.74% and 84.39% in the 75 and 100 tilapia m^{-3} stocking densities, respectively. Consequently, the monthly relative and specific growth rate and feed conversion ratio were significantly (p < 0.05) higher in 50 tilapia m^{-3} stocking density fishes for the first, third, and fourth months. Gross production was comparable between 50 and 75 tilapia m^{-3} stocking densities but was significantly (p < 0.05) better than 100 m^{-3} stocking density. Net production was significantly (p < 0.05) higher at 50 tilapia m^{-3} stocking density group than those of 75 and 100 tilapia m^{-3} stocking densities. The best feed conversion ratio (1.60) was in the 50 tilapia m^{-3} stocking density group (p < 0.05) than those of 1.87 and 2.44 for the stocking of 75 and 100 tilapia m^{-3}, respectively. Benefit-cost ratio and net profit were significantly (p < 0.05) better at 50 and 75 tilapia m^{-3} than at 100 tilapia m^{-3} stocking density. Therefore, considering maximum outputs, benefits, and performances, we recommend stocking density at 50 mono-sex tilapia m^{-3} for the best growth, cost-effective production, and highest-economic return from 120 days of grow-out net cages in the riverine culture system.

Introduction

In 2020-2021, Bangladesh was placed third and fifth in inland fish and aquaculture production country (FAO, 2018). In 2020-21, in total 4.621 million tones of fish produced, of which aquaculture contributed 57.10% of the total fish production (DoF, 2022). This magnificent fish-producing progress has substantially increased national annual fish production from 18.07 kg per person in 2009-10 to 22.85 kg per person in 2020-21 within a decade (DoF, 2011 and 2022). The success of daily national fish consumption of 62.58

*Corresponding author: <mnnaser@du.ac.bd>

[1]*Part of PhD research at DU. Bangladesh Fisheries Research Institute, Riverine Station, Chandpur, Bangladesh*

g/day/person against the set target of 60 g/day/person as animal protein is a challenge to maintain the protein sources in diets for the growing population in the future. Furthermore, the aquaculture sector plays a vast role in income generation and nutritional security through the support of fish entrepreneurs such as fish hatcheries, nursery owners, fish seed/fry and fingerlings suppliers, fish feed and other materials sellers, smallholders and improvised fish grow-out farmers, fish wholesalers and retailers in improving household income, employment opportunities, livelihoods and resilience to climate change adaptation.

Genetically Improved Farmed Tilapia (GIFT) is a selection-based improved strain of Nile tilapia, *Oreochromis niloticus,* one of the most imperative fish farming candidates worldwide. In Bangladesh, it was revealed that the GIFT strain had the better growth rate, yield, feed conversion ratio (FCR), and benefit-cost ratio (BCR) in monoculture (growth rate: 3.3% day^{-1}; yield: 8.1 hac/cycle; FCR: 1.5; BCR: 1.7) and polyculture (growth rate: 3.1% day^{-1}; yield: 12.7 hac/cycle; FCR: 2; BCR: 2) systems than the non-GIFT tilapia cultured in monoculture (growth rate: 2.6% day^{-1}; yield: 6.2 hac/cycle; FCR: 1.8; BCR: 1.1) and polyculture (growth rate: 2.4% day^{-1}; yield: 10.2 hac/cycle; FCR: 3.1; BCR: 1.5) systems (Tran et al., 2021). Bangladesh has achieved 3rd and 4th positions among Asian and global tilapia production, respectively (DoF, 2020). It is a suitable aquaculture species in earthen pond settings for monoculture and polyculture, integrated culture in rice fields, and cages culture systems across the country (Kunda et al., 2021). One of the potential production strategies of this species involves with cage culture system that has been practiced in many countries like Bangladesh, Thailand, Vietnam, Philippines, Laos, Pakistan, India, Nepal, Cambodia, Malaysia, Indonesia, Fiji, Papua New Guinea, Ghana, Ivory Coast, Nigeria, Uganda, Zambia, Zimbabwe, Ethiopia and Brazil (Bhujel, 2019; Fialho et al., 2021; Gibtan et al., 2008).

Cage tilapia farming in ponds, reservoirs, lakes, and riverine ecosystems should be received much attention in Bangladesh because it provides good production and is considered a profitable aquaculture business from vast wetlands of the country. It is likely to ensure sustainable utilization of huge open water resources across the country (Barman et al., 2003; Naser and Khatun, 2006, 2007; Ali et al., 2011, 2019; Hossain et al., 2014; Kunda et al., 2021; Moniruzzaman et al., 2015; Shamsuddin et al., 2022). Also, this technology can be implemented in a brackish water environment (Ninh et al., 2014). In the 1980s, this technology was first initiated in cages at the Kaptai Lake, Rangamati; and later on, it was demonstrated in ponds, lakes, and riverine systems in Bangladesh (Ahmed et al., 2014; Hossain et al., 2017). The management strategies include stocking density, animal stock size, pelleted feed crude protein level, daily feeding levels, etc., influencing its viability, profitability, and sustainability. Thus, the optimal level of resource use could lead to the success and prerequisites for the community-level implementation of this technology.

An ideal stocking density is paramount in tilapia cage culture that provides higher growth andsurvival, subsequently increasing tilapia productivity and ensuring maximum economic benefits. Some studies have been tested to identify the best stocking density for Nile tilapia *O. niloticus* culturing in cages in riverine systems. In addition, Naser and Khatun (2007) recommended 200 medium-sized tilapia fingerlings per cubic meter for pond cage culture. Ali et al. (2019) found an optimal stocking density of 150 small fingerlings m^{-3} cage in the Padma River system, while Kunda et al. (2021) observed that the stocking of 40 and 60 tilapia m^{-3} of larger sized tilapia stocked higher growth, productivity, and economic return compared to the density of 80 individuals m^{-3}. These authors did not take the higher density of 100 fish m^{-3} that should be examined for open-water fish cage culture. Moniruzzaman et al. (2015) identified that a density of 50 fish m^{-3} was optimal for tilapia growth rate, feed conversion ratio, and net returns than the medium to high densities of 75, 100, and 125 fish m^{-3} in cages. But they produced relatively smaller marketable sizes of tilapia because they had stocked small sizes of fish, on average 15.20 g in cages. Similarly, Gibtan et al. (2008) showed that a stocking density of 50 individuals m^{-3} in cages had given higher growth and better feed conversion ratio than the higher density of 100, 150, and 200 tilapia m^{-3} in cages. Despite stocking of bigger size of tilapia at 45.76 g, these authors failed to achieve a suitable marketable size of tilapia after 150 days of culture; this was likely due to the minimum level of feed application at 2% of body weight as well as a powder form of feed. This study compared three densities such as low (50tilapia m^{-3}), medium (75 tilapia m^{-3}), and higher density (100 tilapia m^{-3}) of fishes in riverine cages. It assessed the density effects on the growth rate and production survival of *O. niloticus* at the River Dakatia, Chandpur. This study also addressed the benefit-cost ratio and water quality parameters to properly understand the tilapia-cage culture economics and the suitability of riverine tilapia cage culture systems in Bangladesh. This study's insights will help the farmers and policymakers extend cage tilapia culture in the riverine system.

Materials and Methods

Source of experimental fish and acclimation

Approximately 14,000 mono-sex Nile Tilapia *O. niloticus* fingerlings were acquired from the nursery ponds of Bangladesh Fisheries Research Institute (BFRI), Riverine Station, Chandpur. These tilapia fingerlings were healthy and naturally active. Before this experiment, fingerlings were acclimatized in the floating cages for a week. The fingerlings were fed tilapia pellet feed twice daily (09:00 and 16:00 h) to apparent satiation during acclimatization, containing 30% crude protein and 5% fat. Then these tilapia fingerlings were distributed among the experimental cages according to the experimental design.

Cage setting, experimental protocol, and feeding schedule

The experimental cages were installed in the River Dakatia, Roghunathpur, and Chandpur. Floating net cages were installed as the outer and inner layer, being an area of 3 m × 3 m × 2 m made of the plastic net (mesh size 2.5 cm) and knot-less polyethylene net (mesh size 1.1 cm), which were installed as outer and inner layer, respectively. The frames of net cages were made with GI pipe. The 250-liters capacity of empty iron drams was attached for floating the cages. The experimental duration was 120 days. The experiment consisted of three treatments with three replicas for each density. The treatments were low stocking density (50 fishes m^{-3}, i.e., in total 900 tilapia fingerlings per net cage), medium stocking density (75 fishes m^{-3}, i.e., in total 1,350 tilapia fingerlings per net cage), and high stocking density (100 fishes m^{-3}, i.e., in total 1,800 tilapia fingerlings per net-cage). The experimental tilapia fingerlings had an average initial weight of 28.92±8.37 g. The fish were fed twice daily with tilapia commercial floating pellets (30% crude protein, 5% fat). The daily feeding was done with a half ration of the feed in the morning (09:30 to10:00 h) and the rest of the half in the afternoon (16:00 to 16:30 h). The feeding rate was at 5% of the total body weight for the first and second months, then at 4% for the third month, and finally, in the fourth month, at 3% of the total body weight of the cage fish. On each sampling day, fish were visually checked for their overall physical condition to observe any dead or diseased fish in each cage. The sampling was performed each month to adjust the feeding ratio and determine the growth performance, which will be discussed in the next section below. Each cage net was cleaned once a month.

Tilapia harvesting, estimation of growth performance

A monthly sample of 50 tilapia was randomly collected from each cage, and their live body weights were measured. After the 4-month grow-out phase, the final harvest was performed, while all tilapia were counted to estimate the tilapia survival. One hundred fifty tilapias (50 tilapia from each experimental cage) were randomly selected, and the live body weight was measured to determine the growth performance. Tilapia survival, final weight, weight gain, relative growth rate, specific growth rate, production, and feed conversion ratio were calculated using the following formulas.

Survival rate (%) = (Final live tilapia count / Initial live tilapia count) × 100.

Gross production = Mean final tilapia weight (kg) × final live tilapia harvested.

Net production = Mean final tilapia weight (kg) – initial tilapia weight (kg) × final live tilapia harvested.

Weight gain (g) = mean final weight tilapia – mean initial weight.

Relative growth rate (RGR) (%) = $(W_2-W_1) / W_1 \times 100$. Where, W_1 = Live body weight of tilapia (g) at time T_1 (day).W_2 = Live body weight of tilapia (g) at time T_2 (day)

Specific growth rate (SGR) (% day^{-1}) = $[(\ln W_1 - \ln W_0)]/ t\times100$, where, W_1 = final weight of tilapia, W_0 = initial weight of tilapia, and t = culture days

Feed conversion ratio (FCR) = total feed weight offered / (final fish biomass - initial fish biomass).

Economic analysis

An economic analysis was performed to estimate the mono-sex Nile tilapia *O. niloticus* grow-out production economics of the riverine cage culture system. The profitability of tilapia grow-out production in cages was calculated using the following formula:

$R = PbiBi – (PxjXj + TFC)$

where,

R = net return, *Pbi* = unit price of *i*th products (BDT kg^{-1}), *Bi* = quantity of *i*th products sold (Kg BDT^{-1}), *Pxj* = unit price of *j*th inputs, *Xj* = quantity of *j*th inputs, *i* = 1, 2, 3, … n, *TFC* = fixed costs (Hosain et al., 2021a,b).

BCR = Total income / total expenditure.

Profit (BDT) = Total income in

BDT = Total expenditure in BDT.

Water quality parameters

Cage water quality parameters such as temperature, pH, water transparency, water depth, current river water velocity, dissolved oxygen, free carbon dioxide, total alkalinity, total hardness, ammonia-N, and nitrite-N were determined every 14 days interval. These were done for all cages between 08:30 to 11:00 hours. The determination procedure of these water quality variables was described by Hossain et al. (2022). In brief, water temperature (°C) was estimated with a centigrade thermometer. Water transparency was measured with the aid of a Secchi disk. A HANNA pH meter (Model HI 8424, Italy) was used to estimate the cage water pH. The dissolved oxygen (DO) values were determined with the Lutron DO meter (Model DO 5509, Singapore). The HACH water quality testing kit (Model FF-2, USA) was used to determine the cage water ammonia-N, nitrite-N, total alkalinity, hardness, and Free carbon dioxide.

Statistical analysis

One-way analysis of variance (ANOVA) was carried out to check the differences among three stocking density treatmentsusing a software package R version 3.0.0 for Windows.Pearson correlation coefficients were used for the inter-relationship of water quality parameters using SPSS (version 25.0 for Windows). The mean values of tilapia growth performance parameters, production, and culture economics, including BCR, were compared between the treatments using the least significant difference (LSD) and coefficient of variation.

Results and Discussion

Water quality parameters

The maximum water temperature was 32.1°C in October, and the minimum was 31.1°C in July (Table 1). Cage adjacent water depth of the River Dakatia varied from 5.0 m in June to 5.5 m in October. The current velocity of cage water ranged from 25 cm sec^{-1}in June to 37 cm sec^{-1} in October (Table 1). The highest value of water transparency was 71 cm in October, and the lowest was 38 cm in June (Table 1).

The current velocity of cage water had a significant positive correlation with water transparency (p<0.05; r = 0.951) (Table 2). Dissolved oxygen ranged from 5.68 mg L^{-1} in July to 7.2 mg L^{-1} in June (Table 1). The free CO_2 values of the River Dakatia cage water varied from 4.2 mg L^{-1} in October to 4.6 mg L^{-1} in August. The cage water pH values fluctuated between 7.0 in July to 8.4 in October. The cage water pH values showed a strong positive correlation with water temperature (p<0.05; r =0.927) and water current velocity (p<0.05; r =0.916) (Table 2). The lowest total hardness of cage water was 46.32 mg L^{-1} in September, and the highest was 54.28 mg L^{-1} in June (Table 1). The total alkalinity of cage water varied from 52.62 mg L^{-1} in September to 68.62 mg L^{-1} in June (Table 1). The total alkalinity of cage water in the River Dakatia had a significant positive correlation with dissolved oxygen (p<0.01; r=0. 967) and total hardness (p<0.05; r=0.944) (Table2). The ammonia-N concentration of cage water varied from 0.002 mg L^{-1} in September to 0.006 mg L^{-1} in June (Table 1). Nitrite-N_2 was not recorded during the study period (Table 1). In this study, the water quality variables of cages in the River Dakatia were within reasonable limits for *O. niloticus* (Ross, 2000). Additionally, the quality parameters, i.e., water temperature, pH, dissolved oxygen, free CO_2, total alkalinity, total hardness, ammonia-N, and NO_2-N, were more or less similar to the following previous studiesin the River Dakatia, Meghna, Gumti, Titas and Hoara, Bangladesh (Hossain et al., 2022; Ahmed et al., 2014).

Table 1. Monthly mean values of water quality parameters of cage water during mono-sex Nile Tilapia *Oreochromis niloticus* cultured in the River Dakatia, Roghunathpur, Chandpur

Parameters	Months						
	June	July	August	September	October	Range	Mean ±SD
Depth of water (m)	5	5.1	5.3	5.4	5.5	5-5.5	5.26±0.21
Current velocity (cm sec^{-1})	25	28	29	31	37	25-37	30±4.47
SD transparency (cm)	38	49	56	63	71	38-71	55.40±12.70
Water temperature (°c)	31.5	31.1	31.3	31.8	32.1	31.1-32.1	31.56±0.39
DO (mg L^{-1})	7.2	5.68	5.82	5.74	6.04	5.68-7.2	6.10±0.63
Free CO_2 (mg L^{-1})	4.58	4.42	4.6	4.52	4.2	4.2-4.6	4.46±0.16
pH	7.25	7	7.5	7.75	8.4	7-8.4	7.58±0.54
Total hardness (mg L^{-1})	54.28	48.12	47.2	46.32	52.68	46.32-54.28	49.72±3.53
Total alkalinity (mg L^{-1})	68.62	53.72	54.37	52.62	60.14	52.62-68.62	57.89±6.67
Ammonia-N (mg L^{-1})	0.006	0.004	0.004	0.002	0.002	0.002-0.006	0.004±0.001
Nitrite-N (mg L^{-1})	0	0	0	0	0	0	0

Table 2. Correlation matrix of water quality parameters in cage water when culturing mono-sex *Oreochromis niloticus* in the River Dakatia, Roghunathpur, Chandpur

	WCV	SDT	WT	DO	CO_2	pH	TH
SDT	0.951*						
WT	0.773	0.697					
DO	-0.456	-0.632	0.081				
CO_2	-0.828	-0.644	-0.582	0.251			
pH	0.916*	0.861	0.927*	-0.153	-0.657		
TH	0.004	-0.280	0.338	0.832	-0.310	0.194	
TA	-0.263	-0.493	0.202	0.967**	0.014	0.008	0.944*

WCV: water current velocity; SDT: secchi disk transparency; WT: water temperature; TDS: total dissolved solids; DO: dissolved oxygen; CO_2: carbon dioxide; pH: negative hydrogen ion concentration; TH: total hardness; TA: total alkalinity. *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

Growth, survival, production, and economics

Tilapia final weight (376.72 g) was Significantly (p< 0.05) higher in the low stocking density (50 fish m^{-3}) group than those of 276.64 g and 201.15g in the medium stocking density (75 fish m^{-3}) and high stocking density (100 fish m^{-3}), respectively (Table 3 and 5). In this study, the market-desirable size of tilapia (376.72 g) has been achieved in low stocking density treatment after 120 days of culture period by the stock of 28.92 g weight of fish. This result is better than those reported by Gibtan et al. (2008) and Moniruzzaman et al. (2015). They obtained 219.71 g and 255.53 g body weight tilapia in 50 ind. m^{-3} stocking density after 150 and 120 days of culture period by stocked of 45.76 g and 15.20 g tilapia, respectively (Gibtan et al., 2008; Moniruzzaman et al., 2015). The final SGR and RGR were substantially (p<0.05) betterin the low stocking density (50 fish m^{-3}) treatment then, followed by the medium (75 fish m^{-3}) and high (100 fish m^{-3}) density groups, respectively (Table 3 and 5). Kunda et al. (2021) stated that the higher final weight and SGR of mono-sex Nile tilapia had had in the 40 and 60 fish m^{-3} stocking densities than 80 fish m^{-3} stocking density when the suitable density of tilapia was optimized in the cages culture condition at the River Gurukchi, Gowainghat, Sylhet, Banbladesh. The monthly and final weight gains were significantly better at the low stocking density (50 fish m^{-3}) treatment than in the medium (75 fish m^{-3}) and high (100 fish m^{-3}) densities (p< 0.05) (Table 3, 4 & 5). Similarly, better RGR and SGR were found in the low-density group than in the medium and high-density groups in the first month (p < 0.05). At the same time, the RGR and SGR were comparable (p>0.05) between the medium and high stocking density groups (Table 4). In the second month, the RGR and SGR were higher (p<0.05) at the medium stocking density group than at the low and high stocking densities (Table 4). In the third month, the RGR and SGR were better (p<0.05) in the 50 individuals m^{-3} stocking density treatment than these, followed by the densities of 75 and 100 individuals m^{-3}, respectively (Table 4). For the fourth month, the RGR and SGR were similar (p>0.05) between the densities of 50 and 75 individuals in m^{-3} treatments. However, these lower and medium stocking density treatments achieved significantly better tilapia growth than in the high stocking density group (p<0.05) (Table 4).

Table 3. Growth performance of mono-sex Nile tilapia *Oreochromis niloticus* cultured under the different stocking densities in the River Dakatia, Roghunathpur, Chandpur during 120 days

Parameters	Stocking density			Range	Mean ± SD
	50 Tilapia m^{-3}	**75 Tilapia m^{-3}**	**100 Tilapia m^{-3}**		
Initial weight (g)	28.92	28.92	28.92	28.92 - 28.92	28.92±0
Final weight (g)	376.72	276.64	201.15	201.15 - 376.72	284.84±88.07
Weight gain (g)	347.80	247.72	172.23	172.23 - 347.80	255.92±88.07
Relative growth rate (%)	94.63	80.14	66.62	66.62 - 94.63	80.46±14.00
Specific growth rate (% day^{-1})	2.13	1.87	1.61	1.61- 2.13	1.87±0.26
Food conversion ratio	1.59	1.87	2.43	1.59 - 2.43	1.96±0.43
No. of fish harvested	881	1171	1519	881 - 1519	1190.33±319.44
Survival (%)	97.92	86.73	84.38	84.38 - 97.92	89.68±7.23
Gross production (kg cage^{-1})	331.96	323.92	305.54	305.54 - 331.96	320.47±13.54
Net production (kg cage^{-1})	306.48	290.05	261.60	261.60 - 306.48	286.04±22.71
Net profit (BDT cage^{-1})	17215	9740	2211	2211 - 17215	9722±7502.01
Benefit-cost ratio	1.81	1.37	1.07	1.07 - 1.81	1.42±0.37

Feeding: 5-3% body weight feed daily in each treatment.

Table 4. Monthly growth performance parameters of mono-sex Nile Tilapia *Oreochromis niloticus* cultured under various stocking densities in cages of River Dakatia, Roghunathpur, Chandpur during 120 days

Stocking density (Tilapia m^{-3})	Monthly growth parameters															
	Mean weight gain (g)				**Mean relative growth rate (%)**				**Mean specific growth rate (% day^{-1})**				**Mean feed conversion ratio**			
	Months				**Months**				**Months**				**Months**			
	1st	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**
50	40.5^a	85.1^a	125.5^a	96.5^a	140.2^a	122.5^b	81.2^a	34.5^a	2.92^a	2.66^b	1.98^a	0.98^a	1.06^b	1.22^a	1.47^c	2.64^b
75	24.9^b	75.7^b	76.83^b	70.1^b	86.16^b	141.0^a	9.45^b	33.9^a	2.06^b	2.93^a	1.55^b	0.97^a	1.76^a	1.06^b	2.02^b	2.65^b
100	22.4^b	63.6^c	46.66^c	39.5^c	77.46^b	123.9^b	40.6^c	24.4^b	1.91^b	2.68^b	1.13^c	0.73^b	1.93^a	1.20^a	2.95^a	3.67^a
LSD	4.45*	4.36**	7.84***	15.1*	15.39**	13.49*	6.81**	6.31*	0.27*	0.19*	0.14*	0.16*	0.30*	0.07*	0.12*	0.52*
CV (%)	7.61	2.92	4.72	11.00	7.60	5.22	5.64	10.20	5.90	3.42	4.46	8.81	9.41	2.81	2.76	8.74

Means bearing the same letter(s) in a column do not differ significantly. $^{***}p<0.001$; $^{**}p<0.01$; $^{*}p<0.05$.

In this study, the best final feed conversion ratio (FCR) at 1.6 was obtained in the low-density (50 fish m^{-3}) treatment, and it was followed by 1.87 and 2.44 in the medium-density (75 fish m^{-3}) and high-density (100 fish m^{-3}) groups, respectively (Table 3 and 5). In the first month, a better FCRwas recorded in the low-density treatment than in medium and high-density treatments ($p<0.05$), while FCRs were not significantly different between medium and high-density groups ($p<0.05$) (Table 4). Whereas, for the second month, the FCR was ($p<0.05$) better in the medium stocking density treatment than in low and high stocking treatments. In the third month, the best FCR was found in the low-density group than it, followed by medium and high-density groups, respectively (Table 4). In the fourth month, the FCR was similar ($p>0.05$) between low and medium stocking density treatments; these were significantly ($p<0.05$) better than the high stocking density group (Table 4). This study shows that the low and medium stocking density groups have better FCR than the high-density tilapia cage culture throughout the trial. This finding concurred with Gibtan et al. (2008), who recorded more than two-fold higher FCR when the Nile tilapia density increased from 50 individuals m^{-3} (FCR: 2.48) to 100 individuals m^3 (FCR: 5.64).

The mean survival rate at 97.92% was significantly ($p<0.05$) higher in the low (50 fish m^{-3}) stocking density treatment then it followed by 86.73% and 84.38% for the medium density (75 fish m^{-3}) and the higher (100 fish m^{-3}) stocking densities, respectively (Table 3 and 5). In this study, tilapia survival has remained within the feasible range (84.38-97.92%). These results have in agreement with Gibtan et al. (2008) and Kunda et al. (2021), who have obtained the range of *O. niloticus* survival from 94.0% to 98.17% when optimizing suitable stocking density for cage-tilapia grow-out production. Their trials tested various stocking densities of 40, 60, and 80 individuals m^{-3}(Kunda et al., 2021) and 50, 100, 150, and 200 individuals m^{-3} (Gibtan et al., 2008). However, their studies have indicated that the low to higher tilapia densities (40-200 ind. m^{-3}) provide excellent tilapia survival in net cage-tilapia culture in the lake (Gibtan et al., 2008) or in a riverine cage culture system (Kunda et al., 2021).

Mean gross production was similar ($p>0.05$) between the low and medium stocking density groups, and these were significantly ($p<0.05$) better than that of the high stocking density group (Tables 3 and 5). Significantly ($p<0.05$), a higher mean net production (306.48 kg $cage^{-1}$) was in the low-density group then it followed by 290.05 and 261.60 kg $cage^{-1}$ in the medium and high-density treatments, respectively (Tables 3 and 5). Benefit-cost ratio and net profit were better ($p<0.05$) in the low stocking treatment than those in the medium and high tilapia densities (Tables 3 and 5). This study obtained higher net production and economic returns in the low-density tilapia stocking group than in the medium-density and high-density riverine cage culture systems. These were due to the better mono-sex Nile tilapia final weight/growth, survival, and FCR in the low stocking density culture. Moreover, aquaculture candidates` growth, survival, and FCR in feeding costs are the key drivers in higher production, economic returns, and sustainability (Garcia et al., 2017; Hosain et al., 2021b). Therefore, this study suggests a stocking density of 50 fish m^{-3} in the cages for better growth, survival, production, and economic return of mono-sex *O. niloticus* intensive production in the riverine systems in Bangladesh.

Table 5. Mean values of growth performance parameters of mono-sex Nile Tilapia *Oreochromis niloticus* awell as cage economics when cultured using various stocking densities in cages in the River Dakatia, Roghunathpur, Chandpur during 120 days

Stocking density (Tilapia m^{-3})	Parameters									
	Mean FW (g)	Mean WG (g)	Mean RGR (%)	Mean SGR (% day^{-1})	Mean FCR	Mean surviva l (%)	Mean GR (kg)	Mean NP (kg)	Mean BCR	Mean net profit (Tk)
50	376.72[a]	347.80[a]	94.63[a]	2.13[a]	1.60[c]	97.92[a]	331.96[a]	306.48[a]	1.81[a]	17215[a]
75	276.65[b]	247.73[b]	80.17[b]	1.87[b]	1.87[b]	86.74[b]	323.92[a]	290.06[b]	1.37[b]	9740[b]
100	201.15[c]	172.23[c]	66.63[c]	1.61[c]	2.44[a]	84.39[c]	305.54[b]	261.61[c]	1.07[c]	2211[c]
LSD	12.95***	12.95***	2.17***	0.03***	0.14***	1.25***	10.43**	10.72***	0.05***	1282.55***
CV (%)	2.28	2.53	1.35	0.85	3.53	0.70	1.63	1.88	1.81	6.60

FW: final weight; WG: weight gain; SGR: specific growth rate; FCR: feed conversion ratio; GR: gross production; NP: net production; BCR: benefit-cost ratio. The Means bearing the same letter(s) in a column do not differ significantly. ***indicates $p< 0.001$; **indicates $p< 0.01$.

Conclusion

This study indicates that, in river net-cages, mono-sex Nile tilapia *O. niloticus* growth, survival, FCR, and production were best in the density of 50 tilapia m^{-3}, compared to 75 and 100 tilapia m^{-3} stocking densities. These better growth, productivity, and lower feed costs have documented the increasing economic return in the density of 50 tilapia m^{-3} treatments. This study suggests a density of 50 fish m^{-3} for higher growth, yield, and economic return of mono-sex Nile tilapia for intensive grow-out net-fish cages in the riverine ecosystem. Future research should be conducted on the super-intensification of GIFT in lake or riverine cages to examine the partial harvest and their relation to production economics and household nutrition whenadopted at the community levels. Moreover, these studies should address cage culture's environmental issues while using the lake or riverine systems.

Acknowledgments

The first author (MRAH) acknowledged the funding for Ph.D. research through BARC-NATP scholarships. The support from Bangladesh Fisheries Research Institute and Zoology, DU-Bergen University laboratory facilities from Zoology, University of Dhaka are acknowledged.

References

Ahmed T, Hasan JS, Hossain MRA, Haidar I, Rubel ASA and Pramanik MH. Assessment on the impact of dietary probiotic supplementation on growth indices of mono-sex tilapia (*Oreochromis niloticus*) cage culture at Dakatia River, Chandpur, Bangladesh. *World J. Fish Mar. Sci.* 2014; 6(5): 441-446.

Ali MS, Hossain MA and Naser MN. Optimization of stocking density for cage farming of Nile Tilapia (*Oreochromis niloticus* L.) in the river in ecosystem of northern Bangladesh. *EBAUB J.* 2019; 1: 57-64.

Ali MS, Hossain MA and Naser MN. Species suitability for small scale cage aquaculture in river ecosystem of northern Bangladesh. *Bangladesh J. Prog. Sci. Tech.*2011; IX (2): 197-200.

Barman BK, Little DC and Janssen J. Tilapia culture systems in Bangladesh. *Glob. Aquac. Advocate*. 2003; 6(4): 31–33.

Bhujel RC. Cage culture of monosex tilapia for food and financial security. Klinbunga S, Karoonuthaisiri N. and Piyapattanakorn S.(eds.) In: *Proceedings of the Sixth International Symposium on Cage Aquaculture in Asia*. 2019; pp. 19-28.

DoF. Yearbook of Fisheries Statistics of Bangladesh 2009-2010. Fisheries Resources Survey System, Department of Fisheries, Bangladesh Ministry of Fisheries and Livestock, Government of the

People's Republic of Bangladesh, 2011; 27: p 43.

DoF. Yearbook of Fisheries Statistics of Bangladesh 2020-21. Fisheries Resources Survey System, Department of Fisheries, Bangladesh Ministry of Fisheries and Livestock, Government of the People's Republic of Bangladesh, 2022; 37: p141.

FAO. The State of World Fisheries and Aquaculture. Meeting the sustainable development goals., Food and Agriculture Organization of the United Nations, Rome. *Licence*: 2018; CC BY-NC-SA 3.0 IGO.

Fialho NS, Valenti WC, David FS, Godoy EM, Proença DC, Roubach R and Wolff Bueno G. Environmental sustainability of Nile tilapia net-cage culture in a neotropical region. *Ecol. Indic*. 2021; 129(3-4):108008.

Garcia F, Sabbag OJ, Kimpara JM, Romera DM, Sousa NS, Onaka EM and Ramos IP. Periphyton-based cage culture of Nile tilapia: An interesting model for small-scale farming. *Aquaculture*. 2017; 479: 838-844.

Gibtan A, Getahun A and Mengistou S. Effect of stocking density on the growth performance and yield of Nile tilapia *Oreochromis niloticus* (L., 1758) in a cage culture system in Lake Kuriftu, Ethiopia. *Aquac. Res.* 2008; 39(13): 1450-1460.

Hosain ME, Amin SMN, Kamarudin MS, Arshad A and Karim M. Effects of carbon sources on the culture of giant river prawn in biofloc system during nursery phase. *Aquac. Reports*. 2021a; 19: 100607.

Hosain ME, Amin SMN, Kamarudin MS, Arshad A and Karim M and Romano N. Effect of salinity on growth, survival, and proximate composition of *Macrobrachium rosenbergii* post larvae as well as zooplankton composition reared in a maize starch based biofloc system. *Aquaculture*. 2021b; 533: 736235.

Hossain MRA, Hosain ME, Tabassum A and Naser MN. Effects of stocking density on production performance of Nile Tilapia (*Oreochromis niloticus*) grow-out culture in cages. *Bangladesh J. Zool.* 2022; 50(2): 239-250.

Hossain MRA, Rahman MA, Akter S, Hosain ME and Naser MN. 2017. Intervention of tilapia cage culture in the River Dakatia: Threaten or blessed to local fish diversity. *Int. J. Fish. Aquat. Stud.* 2017; 5(1): 228-232.

Hossain, MAR, Naser, MN, Hoq, ME, and Islam, MS. The fry/fingerling production of Tilapia: Hatchery and Culture Management. A training manual (in Bengali) 2014. Bangladesh Fisheries Research Forum, Dhaka, Bangladesh, p 40.

Kunda M, Pandit D and Harun-Al-Rashid A. Optimization of stocking density for mono-sex Nile tilapia (*Oreochromis niloticus*) production in riverine cage culture in Bangladesh. *Heliyon*, 2021; 7(11): e08334.

Moniruzzaman M, Uddin KB, Basak S, Mahmud Y, Zaher M and Bai SC. Effects of stocking density on growth, body composition, yield and economic returns of monosex tilapia (*Oreochromis niloticus* L.) under cage culture system in Kaptai Lake of Bangladesh. *J. Aquac. Res. Dev.* 2015; 6(8): 1000357.

Naser MN and Khatun T. Easy methods for fish culture in small cages (In Bangla). Extension manual, published by Voluntary Organization for Social Development (VOSD), Lalmatia, Dhaka, Bangladesh, 2006. p 32.

Naser MN and Khatun T. Small scale Tilapia culture in Cages (In Bangla). Extension manual, published by Voluntary Organization for Social Development (VOSD), Lalmatia, Dhaka, Bangladesh, 2007. p 24.

Ninh NH, Thoa NP, Knib W and Nguyen NH. Selection for enhanced growth performance of Nile tilapia (*Oreochromis niloticus*) in brackish water (15-20 ppt) in Vietnam. *Aquaculture*, 2014; 428-429: 1-6.

Ross LG. Environmental physiology and energetics. In: Beveridge, M.C.M., McAndrew, B.J. (Eds.), Tilapias: Biology and Exploitation. Springer, Dordrecht.2000; 89-128.

Shamsuddin M, Hossain MB, Rahman M, Kawla MS, Tazim MF, Albeshr MF and Arai T. Effects of stocking larger-sized fish on water quality, growth performance, and the economic yield of Nile Tilapia (*Oreochromis niloticus* L.) in floating cages. *Agric.* 2022; 12(7): 1-19.

Tran N, Shikuku KM, Rossignoli CM, Barman BK, Cheong KC, Ali MS and Benzie JAH. Growth, yield and profitability of genetically improved farmed tilapia (GIFT) and non-GIFT strains in Bangladesh. *Aquac.* 2021; 536: 736486.