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Density Dependent Growth Performance of *Catla catla* and *Labeo rohita* under Cage Culture at Syphon Headworks, Punjab, Pakistan

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SN contributed to the conceptualization, data curation, investigation, methodology, resources, software, supervision, and writing (review and editing). AMMC was involved in the conceptualization, data curation, formal analysis, investigation, methodology, software, supervision, and validation. MB and SSB contributed to data curation, formal analysis, investigation, methodology, validation, and visualization. UI contributed to data curation, formal analysis, visualization, and writing (original draft and review and editing). Additionally, SI, BI, IA, MM, and AE contributed to data curation and writing the original draft. All authors have thoroughly reviewed and approved the final manuscript for submission.

Key words
Growth parameters, Fish growth, Fish growth potential, Freshwater fish, Caged fish culture, Density-dependent growth

ABSTRACT

The fish is an important part of our food. Fish provide a lot of people with 15% of their dietary protein. In current competitive environment the cage culture of fish is economical and viable alternative of traditional fish farming. Current study evaluated the density dependent growth performance of two fish's viz. *Catla catla* and *Labeo rohita* for a period of 90 days using three stocking densities (2000, 4000, and 6000 fingerlings cage^{-1}). Various growth parameters were used to assess the fish growth under cage culture. The results showed that there was a significant difference ($p < 0.05$) in final mean weights, average condition factor, feed conversion ratio, mean daily weight gain, specific growth rate and mean relative weight gain between these two fish species. Furthermore, *C. catla* performed better in caged environment as compared to *L. rohita* ($p < 0.05$) at all three stocking densities. The comparison of fish growth among different sampling months indicated that fish growth was maximum during 2nd month as compared to 1st and 3rd month of growth trial. Overall, this study provided an insight on cage culture of economically important fish species in Punjab, Pakistan.

INTRODUCTION

In numerous countries worldwide, the aquaculture sector demonstrates a remarkable pace of expansion, surpassing all other industries involved in animal food production. Since 1970, the global average annual growth rate for aquaculture stands at 8.8%, while capture fisheries and terrestrial farmed animal production systems trail behind at 1.2% and 2.8% respectively (Mensah and Attipoe, 2013). The role of fisheries and aquaculture as vital sources of food and income is crucial in addressing worldwide challenges of food and nutrition insecurity, as well as meeting economic demands. In 2013, fish provided approximately 17% of the animal protein consumed by the global population, and by 2014, the average per capita fish consumption worldwide reached 20 kg. Moreover, in 2014, fisheries and aquaculture served as a livelihood for 56.6 million individuals globally (Abaho *et al*., 2020). Aquaculture may hold the key to addressing future challenges of food security and insufficiency, as the projected dramatic increase in the global population, expected to surpass 9 billion by 2050, with approximately 22% of individuals under 40 years of age, poses a significant threat (Ahmad *et al*., 2020; Godfray *et al*., 2010). In order

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to achieve healthy fish and minimize production costs, effective management of fish nutrition feed is crucial in the practice of aquaculture (Hussain *et al*., 2011). Fish is a significant contributor to the global consumption of high-quality protein, providing approximately 15% of dietary protein for at least 2.9 billion people. As the world population continues to grow and capture fisheries face production decline, aquaculture is poised to play a vital role in meeting the escalating demand for protein-rich food. Freshwater sources account for over half of the world's aquaculture production, with China and India, among the most populous nations, leading in terms of production volume (Balkhande and Kulkarni, 2017).

Labeo rohita, commonly known as the Indian major carp, is highly favored in the Indian subcontinent and stands as one of the preferred species. It accounts for approximately 35% of the total carp production in the region (Misra *et al*., 2006). Due to its desirable characteristics such as high commercial value, rapid growth rate, consumer preference, and acceptance of artificial diets, *L. rohita* holds the utmost significance among the three major carp species in India (Pakhira *et al*., 2015). *C. catla*, a cyprinid species, holds significant commercial importance as a commonly consumed food item. It is abundant in Pakistan and is cultured alongside other native major carps and imported Chinese carps (Lone *et al*., 2009). Among the three major carps in India, namely *L. rohita*, *Cirrhinus mrigala*, and *C. catla*, the latter is recognized as the fastest-growing species. *C. catla*, known for its primary diet of zooplankton, plays a vital role in polyculture alongside the other two carp species. Its high nutritional value and delicious taste contribute to its strong market demand (Zehra and Khan, 2013).

Cage culture refers to the practice of rearing aquatic animals, primarily fish, in cages or enclosures placed in open water bodies such as rivers, lakes, reservoirs, or coastal marine areas. Today, cage culture is prevalent in central and Southeast Asian countries, including China, the Philippines, Indonesia, and Thailand (Balkhande, 2019). Cage-based fish production has gained significant popularity among small-scale or resource-limited farmers who seek alternatives to traditional agricultural crops. It provides a favorable opportunity for maximum utilization of existing water resources, eliminating the need for additional investments in water accumulation. Cage aquaculture offers distinct advantages over other aquaculture systems, making it particularly appealing to rural communities with limited resources and land availability (Karnatak and Kumar, 2014). The inherent design of cage units enables the effective utilization of large, communal water bodies, eliminating the need for land ownership or leasing for fish cultivation. The management and harvesting of caged fish are also more straightforward. The culture of fish in cages is thus regarded as a promising aquaculture technology, already proven successful in several other Asian countries (Balkhande, 2019). In the intensive practice of cage culture, the primary challenge lies in identifying suitable species for cultivation. Numerous researchers have conducted studies to explore the potential of carps in cage culture, investigating various variables such as growth, survival, feed utilization, stocking density, feeding ration, and more., especially using catla (Govind *et al*., 1988), rohu and common carp (Kohli *et al*., 2002), Indian major and minor carps (Bhattacharjya *et al*., 2008), *L. rohita* fry (Biswas *et al*., 2015) and carp fry (Sarmah *et al*., 2017). The density of fish stocked in cages significantly influences both the growth and profitability of fish farming. Numerous studies have highlighted the substantial impact of stocking density on various aspects such as growth, survival rates, production levels, behavior, and overall health of fish species like Nile tilapia, rohu, common carp, and pirarucu (de Oliveira *et al*., 2012). Therefore, it is essential to optimize the stocking density of a new potential species for successful cage culture. Elevated density-induced stress triggers numerous physiological, hemato-immunological, and hormonal alterations in the blood metabolism of turbot and rainbow trout (Upadhyay *et al*., 2022).

Cage culture is relatively new in Pakistan with very little understanding of suitable fish species to culture in cages. The present study was conducted to better understand the productivity of two economically important fish species in cage culture.

MATERIALS AND METHODS

Study area and construction of cages

The current study was conducted at Syphon headworks (29°48'1" N; 72°10'33" E), Mailsi, district Vehari, Punjab, Pakistan (Fig. 1A). The selected site satisfied all the necessary criteria for successful cage culture, including adequate water depth and sediment-free conditions.

Fifty cages were constructed and installed at the Syphon headworks. Each cage had a volume of 39.29 m^3. The cages were built using galvanized pipes welded into a frame and floated on the river using rubber drums. The cages were securely equipped with inner netting (0.19-inch mesh size) and outer netting (0.39-inch mesh size) in the backwater of the Satluj River at the Syphon headworks. Ropes were used to anchor the floating cages to the shore, with a distance of 360 inches separating the cages from the shoreline (Fig. 1B). For current study, twenty-four out of fifty cages were selected to explore the growth response under three stocking densities of two fish species in cages culture ecosystem.

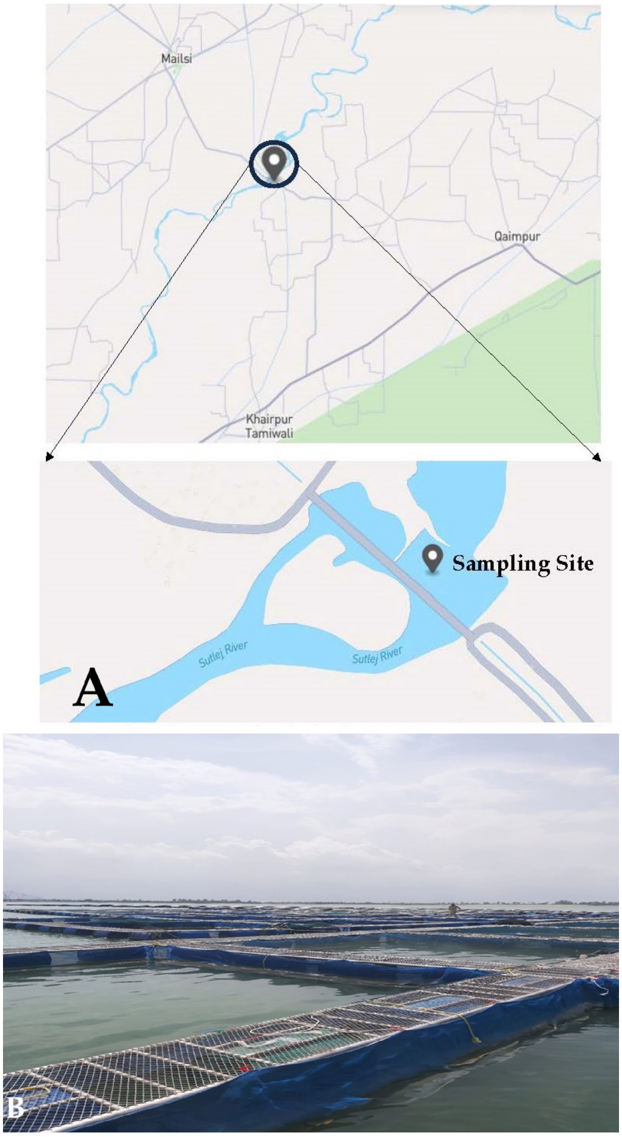

Fig. 1. (A) Location of sampling site at siphon headworks (72° 14′ 56.1″ East, 29° 43′ 35.7″ North) near Malsi, Punjab, Pakistan. Map data © OpenStreetMap contributors, under ODbL. (B) Cage culture used for rearing of studied fish species (*C. catla* and *L. rohita*) at siphon headworks, Punjab, Pakistan.

Cage management plays a crucial role in cage culture following installation. It is imperative to regularly clean the cages prior to feeding in order to eliminate dead fish, uneaten food, and other debris, thereby maintaining a favorable environment for the fish. Additionally, a weekly practice of partially lifting the cages from the water before feeding serves to inspect any potential damage and address any algal blooms present on the cage's surface.

Procedure adopted

Fingerlings of *C. catla* and *L. rohita* were obtained from the Fisheries Complex, Department of Fisheries, Government of Punjab, Pakistan located in Bahawalpur. The fingerlings were carefully conditioned and transported to the study site in oxygenated polythene bags.

Three fish stocking densities of 2000, 4000, and 6000 fingerlings with the density of 50, 100, and 150 fingerlings per cubic meter were used for both fish species. Four cages were stocked with each stocking density of *C. catla* fingerlings with an average weight of 9.76 ± 0.32 g were stocked. Similarly, four cages were stocked with each stocking density of *L. rohita* fingerlings with an average weight of 9.35 ± 0.28 g were stocked.

Following the stocking, the fish were provided with commercial feed (Hi-Tech Aqua feed, containing 30% crude protein) obtained from the local market. The feed was administered based on their body weight, specifically 4% of their body weight. Fish were provided with the selected feed once a day at 7:00 ± 10 am, with the feed being manually administered directly into the cages. The ingredients of this feed had rice bran 50%, maize powder 25%, sunflower cake 10%, sugar syrup 10%, and fish powder 5%.

Periodically, fish were harvested from the cages using a hand net in order to measure their length in centimeters and body weight in grams. The fingerlings were then raised in the cages for duration of 90 days.

Throughout the study, crucial immunological factors including temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO), electrical conductivity (EC), nitrate (NO_3^{-1}), and carbonate (CO_3^{-2}) were assessed. Water temperature and DO levels were measured using S-612 equipment, TDS were measured with BANTE 510, conductivity was measured with S-611L, pH was measured with ST300, and nitrates were measured with Horiba NO_3. Carbonate levels in the water were determined through titration against sulfuric acid, employing phenolphthalein and methyl orange as indicators.

At the conclusion of the study, the experimental cages were emptied and the fish in each cage were sorted, enumerated, and weighed to calculate the average fish weight.

Performance evaluation of fish

Periodic sampling (weekly) of fish was carried out using a hand net to assess the growth analysis of the studied fish species. The mean length (cm) and weight (g) were obtained from random samples of 20 individuals of each fish species. Furthermore, the final mean length, weight and survival level of each fish species were recorded at the time of harvesting. The various growth parameters viz. condition factor, specific growth rate (SGR), feed conversion ratio (FCR), and mean daily weight gain (MWG) were used to determine the growth performance and survival of *C. catla* and *L. rohita*.

The condition factor (K) was computed using the formula $K = BW_{fish}/Sl^3$. Where, BW_{fish} is body weight of fish (g), and Sl is standard length of the fish (centimeters) (Weatherley, 1972). SGR was determined using the formula SGR = $(lnW_f - lnW_i)/t \times 100$. Where, lnW_f is natural logarithm of the average final weight (g), lnW_i is natural logarithm of the average initial weight (g), and t = yime period (days) between lnW_f and lnW_i (Ricker, 1975). FCR was determined using formula suggested by Castell and Tiews (1981). FCR = DW_{feed}/WG_{fish} where, DW_{feed} is dry weight of consumed feed (g), and WG_{fish} is wet weight gain (g) (Castell and Tiews, 1981). Due to the difficulties faced in estimating the feed consumption in cage trials of such kind, the amount of feed provided to the fish is considered as feed consumed by the fish for calculation of FCR. MWG was calculated with the formula, $MWG_d = (W_f - W_i)/t$ where, MWG_d is mean daily weight gain, W_f is final weight at harvest (g), W_i is initial weight at stocking (g), and t is duration of the culture period (30 days).

RESULTS

Growth performance of fish species

Table I shows the density defendant growth performance of two fish species (*C. catla* and *L. rohita*) at three densities (2000, 4000, and 6000 fingerlings cage^{-1} (fpc)) over a period of 90 days under caged culture conditions. Various growth performance parameters were applied monthly, to explore the growth rate of two fish species (*C. catla* and *L. rohita*) for a period of 90 days. The growth assessment of studied fish reared in cage culture showed that the final weight of the fish over a period of 90 days, exhibited an increase of 503.37 g (2000 fpc), 374.13 g (4000 fpc), and 257.77 g (6000 fpc) for *C. catla* and 302.98 g (2000 fpc), 246.62 g (4000 fpc), and 171.11 g (6000 fpc) for *L. rohita*. In *C. catla*, the maximum final weight (g) 147.97 ± 4.54 during first month was found at 2000 fpc fish density followed by 4000 and 6000 fpc. Similar results were also found at 2nd and 3rd month for sampling with maximum final weight of 332.97 ± 9.22 g, 384.18 ± 12.52 g respectively. The analysis of K showed that the highest K (0.29 ± 0.05) was observed in 2nd month at 2000 fpc while the lowest K (0.14 ± 0.01) was found at 6000 fpc during 3rd month sampling. Furthermore, during 1st month the highest K (0.26 ± 0.05) was found at 2000 fpc followed by 4000 and 6000 fpc. Similar results were also found during 2nd month and 3rd month samplings with highest K value of (0.29 ± 0.05 and 0.25 ± 0.05) at 2000 fpc for 2nd and 3rd month sampling respectively. The obtained results demonstrated that SGR of *C. catla* for the 1st month was in the order of 2000 fpc (9.05 ± 0.07) > 4000 fpc (8.37 ± 0.04 > 6000 fpc (7.67 ± 0.02). Similar trend of SGR was observed during 2nd month of sampling. However, for 3rd month, it was in the order of 4000 fpc (1.81 ± 0.05) > 2000 fpc (1.44 ± 0.03) > 6000 fpc (1.27 ± 0.04) for *C. catla*. Overall, the maximum SGR (9.05 ± 0.07) was found at 2000 fpc fish density during 1st month while the least SGR

Table I. Effect of three different densities (2000, 4000, and 6000) of *C. catla* in cage culture on the performance of various growth parameters and feed utilization for period of three months.

Growth parameter	No. of fingerlings cage^{-1}		
	2000 fish/ cage	4000 fish/ cage	6000 fish/ cage
First month			
IMW (g)	9.81±0.37^a	10.05±0.45^a	9.41±0.33^a
FMW (g)	147.97±4.54^a	123.97±5.29^b	93.97±2.34^c
K	0.26±0.05^a	0.24±0.04^a	0.19±0.04^b
SGR	9.05±0.07^a	8.37±0.04^b	7.67±0.02^c
FCR	1.07±0.02^c	1.18±0.04^b	1.33±0.03^a
AWG (g)	3.22±0.03^a	3.02±0.04^b	2.82±0.02^c
RWG (%)	93.37±4.15^a	91.89±2.22^b	90.04±2.29^c
Second month			
IMW (g)	147.97±4.54^a	123.97±5.29^b	93.97±2.34^c
FMW (g)	332.97±9.22^a	223.25±7.24^b	182.5±2.45^c
K	0.29±0.05^a	0.23±0.02^b	0.20±0.01^c
SGR	2.7±0.07^a	1.96±0.08^c	2.21±0.04^b
FCR	1.83±0.05^c	2.13±0.08^b	2.48±0.02^a
AWG (g)	3.42±0.03^a	3.18±0.04^b	2.95±0.06^c
RWG (%)	55.56±3.44^a	44.47±4.29^c	48.51±7.37^b
Third month			
IMW (g)	332.97±9.22^a	223.25±7.24^b	182.50±2.45^c
FMW (g)	513.18±17.33^a	384.18±12.52^b	267.18±13.31^c
K	0.25±0.05^a	0.21±0.03^b	0.14±0.01^c
SGR	1.44±0.03^b	1.81±0.05^a	1.27±0.04^c
FCR	2.94±0.04^c	3.27±0.07^b	3.80±0.05^a
AWG (g)	3.45±0.07^a	3.22±0.05^b	2.87±0.03^c
RWG (%)	35.12±5.13^b	41.89±5.72^a	31.69±6.35^b

The different letters (a, b, c) in the same row show the statistical difference (Duncan Multiple Range Test at ($P<0.05$)) among various fish densities for each sampling month. Where, IMW, initial mean weight; FMW, final mean weight; K, condition factor; SGR, specific growth rate; FCR, feed conversion ratio; AWG, average weight gain; RWG, relative weight gain.

(1.27 ± 0.04) was observed at 6000 fpc during 3rd month of sampling. FCR of *C. catla* was observed to be highest at highest fish density (6000 fpc) with the maximum value of 3.80 ± 0.05 at 6000 fpc during 3rd month while least value of 1.07 ± 0.02 during 1st month. The results showed that FCR during 1st month was in the order of 6000 fpc (1.33 ± 0.03) > 4000 fpc (1.18 ± 0.04) > 2000 fpc (1.07 ± 0.02). Similar results were also recorded for 2nd and 3rd month of sampling with the trend of 6000 fpc (2.48 ± 0.02) > 4000 fpc (2.13 ± 0.08) > 2000 fpc (1.83 ± 0.05) for 2nd month and of 6000 fpc (3.80 ± 0.05) > 4000 fpc (3.27 ± 0.07) > 2000 fpc (2.94 ± 0.04) for the 3rd month of fish sampling. The comparison of AWG (g) in *C. catla* after the end of each month, showed that the monthly AWG of 1st month was in order of 2000 fpc > 4000 fpc > 6000 fpc with AWG of 3.22 ± 0.03, 3.02 ± 0.04, and 2.82 ± 0.02 respectively for 1st month. Similarly, during 2nd month the trend was 2000 fpc (3.42 ± 0.03) > 4000 fpc (3.18 ± 0.04) > 6000 fpc (2.95 ± 0.06) and during 3rd month the trend was 2000 fpc (3.45 ± 0.07) > 4000 fpc (3.22 ± 0.05) > 6000 fpc (2.87 ± 0.03). Overall, the highest AWG (3.45 ± 0.07) was found at 2000 fpc during 3rd month and the lowest AWG (2.82 ± 0.02) was found at 6000 fpc during 1st sampling month. The evaluation of mean relative weight gain (RWG) of the studies fish species demonstrated that RWG of *C. catla* for the 1st month was in the order of 2000 fpc (93.37 ± 4.15) > 4000 fpc (91.89 ± 2.22) > 6000 fpc (91.89 ± 2.22). While for the 2nd month it was in the order of 2000 fpc (55.56 ± 3.44) > 6000 fpc (48.51 ± 7.37) > 4000 fpc (44.47 ± 4.29). For the 3rd month the RWG was found to be in the order of 4000 fpc (41.89 ± 5.72) > 2000 fpc (35.12 ± 5.13) > 6000 fpc (31.69 ± 6.35) (Table I).

The results showed that in *L. rohita*, the maximum final weight (g) 119.55 ± 3.21 g during first month was found at 2000 fpc fish density followed by 4000 and 6000 fpc. Similar results were also found at 2nd month for sampling with maximum final weight of 215.76 ± 7.42 g and 312.43 ± 7.23 g, respectively. The analysis of K showed that the highest K (0.41 ± 0.03) was observed in 1st month at 2000 fpc while the lowest K (0.17 ± 0.04) was found at 6000 fpc during 3rd month of sampling. Furthermore, during 1st month the highest K (0.41 ± 0.03) was found at 2000 fpc followed by 4000 and 6000 fpc. However, highest K value (0.32 ± 0.02) for the 2nd month was found at fish density of 4000 fpc while a maximum K value of 0.29 ± 0.03 was found at 200 fpc during 3rd month. The obtained results demonstrated that SGR of *L. rohita* for the 1st month was in the order of 2000 fpc (8.46 ± 2.27) > 4000 fpc (7.33 ± 2.14 > 6000 fpc (6.62 ± 3.17). However different trends of SGR were observed during 2nd month and 3rd month of sampling. Overall, the maximum SGR (8.46 ± 2.27) was found at 2000 fpc fish density during 1st month while the least SGR (1.20 ± 2.63) was observed at 6000 fpc during 3rd month of sampling. The FCR of *L. rohita* was observed to be highest at highest fish density (6000 fpc) with the maximum value of 3.99 ± 0.21 at 6000 fpc during 3rd month while least value of 1.12 ± 0.32 during 1st month. The results showed that FCR during 1st month was in the order of 6000 fpc (1.39 ± 0.12) > 4000 fpc (1.23 ± 0.14) > 2000 fpc (1.12 ± 0.32). Similar results were also recorded for 2nd and 3rd month of sampling with the trend of 6000 fpc (2.53 ± 0.53) > 4000 fpc (2.25 ± 0.27) > 2000 fpc (1.63 ± 0.45) for 2nd month and of 6000 fpc (3.99 ± 0.21) > 4000 fpc (2.97 ± 0.27) > 2000 fpc (2.42 ± 0.14) for the 3rd month of fish sampling. The comparison of AWG (g) in *L. rohita* after the end of each month showed that the monthly AWG of 1st month was in order of 2000 fpc > 4000 fpc > 6000 fpc with AWG of 3.67 ± 0.21, 2.56 ± 0.12, and 1.89 ± 0.14, respectively. Trends were also observed for 2nd and 3rd month of sampling. Overall, the highest AWG (3.67 ± 0.21) was found at 2000 fpc during 1st month and the lowest AWG (1.82 ± 0.11) was found at 6000 fpc during 3rd sampling month. The evaluation of mean relative weight gain (RWG) of the studies fish species demonstrated that RWG of *C. catla* for the 1st month was in the order of 2000 fpc (92.10 ± 5.12) > 4000 fpc (88.91 ± 6.13) > 6000 fpc (44.59 ± 6.14). While for the 2nd month it was in the order of 6000 fpc (47.64 ± 3.44) and 4000 fpc (47.49 ± 3.19) > 2000 fpc (44.59 ± 6.14). During 3rd month the RWG was found significantly higher at 4000 fpc (35.89 ± 5.32) as compared to 2000 fpc (30.94 ± 4.23) and 6000 fpc (30.29 ± 4.16) (Table II).

The study conducted to explore the effect of fish density on the fish growth for a period of 12 weeks under cage culture showed that higher density of fish in a cage significantly reduced the growth of fish. Overall comparison of fish growth in *C. catla* under various densities showed that fish growth performance was highest at density A (2000 fpc) followed by density B (4000 fpc) and least growth was observed at density C (6000 fpc). Week-wise results of fish growth at density A showed that the highest fish growth was observed at week 9, while the lowest fish growth was found at week 10. Highest fish growth at density B was recorded at week 11 and the lowest fish growth was found at week 8. The highest growth at density C was found at week 6 and the lowest growth was observed at week 12 (Fig. 2). Similarly, overall comparison of *L. rohita* growth under various densities showed that the highest growth was found at density A (2000 fpc) followed by density B (4000 fpc) and least growth was observed at density C (6000 fpc). Week-wise results of *L. rohita* growth at density A showed that the highest fish growth was observed at week 3, while the lowest fish growth was found at week 7. The highest growth at density B was found at week 9

Table II. Effect of three different densities (2000, 4000, and 6000) of *L. rohita* in cage culture on performance of various growth parameters and feed utilization for a period of three months.

Growth parameter	No. of fingerlings cage^{-1}		
	2000 fish/ cage	4000 fish/ cage	6000 fish/ cage
First month			
IMW (g)	9.45 ± 0.37^{b}	9.56 ± 0.45^{a}	9.03 ± 0.21^{c}
FMW (g)	119.55 ± 3.21^{a}	86.24 ± 3.12^{b}	65.75 ± 3.51^{c}
K	0.41 ± 0.03^{a}	0.37 ± 0.06^{b}	0.31 ± 0.03^{c}
SGR	8.46 ± 2.27^{a}	7.33 ± 2.14^{b}	6.62 ± 3.17^{c}
FCR	1.12 ± 0.32^{c}	1.23 ± 0.14^{b}	1.39 ± 0.12^{a}
AWG (g)	3.67 ± 0.21^{a}	2.56 ± 0.12^{b}	1.89 ± 0.14^{c}
RWG (%)	92.10 ± 5.12^{a}	88.91 ± 6.13^{b}	86.27 ± 5.12^{c}
Second month			
IMW (g)	119.55 ± 3.21^{a}	86.24 ± 3.12^{b}	65.75 ± 3.51^{c}
FMW (g)	215.76 ± 7.42^{a}	164.23 ± 6.42^{b}	125.57 ± 4.40^{c}
K	0.32 ± 0.02^{a}	0.26 ± 0.04^{b}	0.21 ± 0.04^{c}
SGR	1.97 ± 1.57^{b}	2.15 ± 2.58^{a}	2.16 ± 2.33^{a}
FCR	1.63 ± 0.45^{c}	2.25 ± 0.27^{b}	2.53 ± 0.53^{a}
AWG (g)	3.21 ± 0.13^{a}	2.60 ± 0.20^{b}	1.99 ± 0.15^{c}
RWG (%)	44.59 ± 6.14^{b}	47.49 ± 3.19^{a}	47.64 ± 3.44^{a}
Third month			
IMW (g)	215.76 ± 7.42^{a}	164.23 ± 6.42^{b}	125.57 ± 4.40^{c}
FMW (g)	312.43 ± 7.23^{a}	256.18 ± 9.32^{b}	180.14 ± 5.19^{c}
K	0.29 ± 0.03^{a}	0.21 ± 0.06^{b}	0.17 ± 0.04^{c}
SGR	1.23 ± 2.31^{b}	1.48 ± 2.22^{a}	1.20 ± 2.63^{b}
FCR	2.42 ± 0.14^{c}	2.97 ± 0.27^{b}	3.99 ± 0.21^{a}
AWG (g)	3.22 ± 0.17^{a}	3.07 ± 0.15^{a}	1.82 ± 0.11^{b}
RWG (%)	30.94 ± 4.23^{b}	35.89 ± 5.32^{a}	30.29 ± 4.16^{b}

For statistical details and abbreviations see Table 1.

and the lowest fish growth was observed at week 12. The highest growth at density C was found at week 5 and the lowest growth was observed at week 1 (Fig. 2).

These results indicated that overall *C. catla* performed better under cage culture as compared to *L. rohita* at all three fish densities. Furthermore, these results explored that the fish density is an important factor to be considered in a caged culture of various fish species to get maximum yield of fish.

Water quality parameters

The water quality parameters served as indicators of the environmental conditions during the fish cultivation period in the study. A number of water quality assessment parameters were studied including, water temperature (°C), pH, DO (mg L^{-1}), TDS (mg L^{-1}), EC (µs cm^{-1}), NO_3^- (mg L^{-1}), and CO_3^{-2} (mg L^{-1}). No significant differences ($p > 0.05$) of these water quality parameters were found between the cages housing the two fish species (Table III).

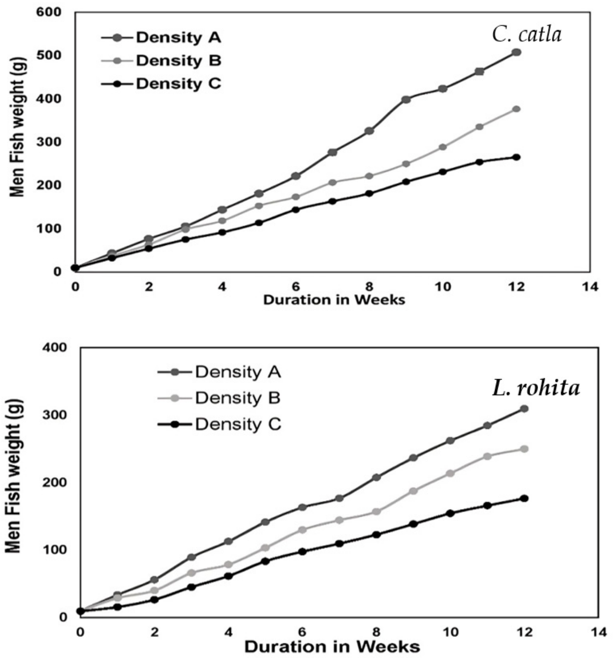

Fig. 2. Growth performance of *C. catla* and *L. rohita* for a period of 12 weeks trial in cage culture with three different densities (A=2000, B=4000, and C=6000).

Table III. Physico-chemical parameters (mean ± S.E) of water at study sites for *C. catla* and *L. rohita* at Syphon headworks, Punjab, Pakistan.

Water parameter	Water for *C. catla* cage	Water for *L. rohita* cage
Temperature (°C)	28.22 ± 0.36	28.27 ± 0.22
pH	7.59 ± 0.03	7.47 ± 0.10
Dissolved oxygen (mg L^{-1})	8.33 ± 0.15	8.71 ± 0.31
Total dissolved solids (mg L^{-1})	62.37 ± 9.94	62.15 ± 6.45
Electrical conductivity (µs cm^{-1})	0.99 ± 0.15	1.15 ± 0.19
Nitrate (NO_3^-; mg L^{-1})	7.80 ± 0.61	8.31± 0.29
Carbonate (CO_3^{-2}; mg L^{-1})	15.54 ± 1.16	15.76 ± 0.97

DISCUSSION

This study evaluated the growth performance of *C. catla* and *L. rohita* under caged culture for a period of 90 days. Similar to current work, many studies have been performed on cage culture activity and growth performance of various fish species. This study is correlated in term of its finding to many other works. *C. catla*, *L. rohita*, *C. mrigala*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, and *Cyprinus carpio* are among important freshwater fishes in cage culture farming (Balkhande and Kulkarni, 2017). Similar study on cage culture was also conducted by (Kohli *et al*., 2002) with *C. catla*, *L. rohita*, *C. carpio, Tor putitora* and *Tor Khudree*. They recommend that the cage culture is viable for raising fingerlings. Another study conducted on cage culture with *C. catla* and *L. rohita* demonstrated that these species are suitable candidates for cage farming in Madhya Pradesh with survival percentage of was 58.9% and 78.7% for *C. catla* and 63.3%, 57.3% and 74.2% for *L. rohita* in cages culture (Tamot and Mishra, 2008). The higher growth rate was achieved in the experiments and may be due to artificial feeding as compared to natural feeding. We have also recorded the higher growth due to the artificial feeding.

Current study demonstrated the growth performance of *C. catla* and *L. rohita* was lower as compared to the fish growth under farm conditions. A similar trend of growth performance was previously shown in Indian major carps (Benakappa and Varghese, 2003; Ramachandran and Ray, 2004). A plausible explanation for lower growth performance of studies fish species in caged culture could be the sensitive nature of these fish species towards the environmental conditions in comparison to other hardy species, like *Oreochromis niloticus* or *C. carpio* (Benakappa and Varghese, 2003). This study is coherent with another study conducted in rivers of Bangladesh with *C. catla*, *C. mrigala* and *L. rohita* collected from two major rivers of Bangladesh, and compared with hatchery culture (Biswas, 2003).

The higher weight gain, daily weight gain and SGR along with better performance of *C. catla* for other growth parameters could be due to greater feed intake, feed acceptance and better efficiency of converting ingested feed into body mass as compared to *L. rohtia*. The results on growth performance under cage culture of the present study is coherent with the study by Luo *et al*. (2014) who demonstrated 472.14% weight gain in caged culture farming. The present result also concurred with Rumpa *et al*. (2016) who reported 952.94% weight gain in a recirculating. Similar SGR as found in the current study was observed earlier with *O. niloticus* in RAS (Luo *et al*., 2014). Higher performance of *C. catla* as compared to *L. rohita* has also been demonstrated in pond polyculture system (Jena and Das, 2011; Verma and Mandal, 2018).

Suitable physico-chemical parameters of water at the study site should be within the acceptable range for major carps, like *C. catla* and *L. rohita* (Sahu *et al*., 2007). The recorded values of various parameters showed that the study site was suitable for studies on fish growth performance and were in accordance to previous studies like by Yusoff *et al*. (2024).

CONCLUSION

In this study, the growth performance of two freshwater fish species, *C. catla* and *L. rohita*, was meticulously observed under cage culture conditions with three different densities. The results showed a notable difference in the growth performance between the two species, with *C. catla* performing better than *L. rohita*. However, it's significant to note that both species exhibited commendable growth rates, proving the viability of cage culture in the given region and could promote sustainable aquaculture. Furthermore, the density of fish in the cages is an important factor which significantly affect the growth and well-being of cultures fish. Higher fish densities may cause reduced fish growth. While this study provides pivotal insights, it is essential to delve further into the potential impacts of different diets on growth performance in future to maximize the output of caged-culture farming.

DECLARATIONS

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Ethical statement

The authors declare that ethical guidelines for the care and use of experimental animals were strictly followed in accordance with institutional and national regulations.

Generative AI and AI-assisted technology statement

The authors declare that no generative artificial intelligence (AI) tools or AI assisted technologies were used in the preparation, writing, data analysis or editing of this manuscript.

Statement of conflict of interest

The authors have declared no conflict of interest.

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