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Influence of Feeding Regimes on Survival, Growth Performance and Production Efficiency of Indian Major Carps Under Semi-Intensive Polyculture System

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Abstract: This study evaluated the effect of different feeding regimes on survival, growth, and production performance of Indian major carps (*Labeo catla*, *Labeo rohita*, and *Cirrhinus mrigala*) in a semi-intensive polyculture system. Fingerlings were stocked in 80 m^2 cemented outdoor tanks at the rate of 1 fish m^{-2}. The experiment was conducted by following a Completely Randomised Design: FR1 (control) with dough feed twice daily at the rate of 2% body weight; FR2, FR3, FR4, and FR5 with pelleted feed @ 2% twice daily, 2% thrice daily, 3% twice daily, and 3% thrice daily, respectively. The water quality parameters remained within optimal throughout the study. FR5 exhibited the highest survival (91.43%), followed by FR4, FR2 and FR3. Maximum net weight gain and specific growth rate were observed in FR5 for catla (33.96 g; 2.28%), followed by rohu (24.70 g; 1.67%). Feed conversion ratio (FCR) and protein efficiency ratio (PER) improved significantly in FR2 and FR3, whereas net fish biomass production was significantly higher in FR3, FR4, and FR5. From the results, we concluded that pelleted feed administered at 2% body weight thrice daily (FR3) represents the optimal feeding strategy for maximising growth performance and production efficiency in semi-intensive carp polyculture systems, balancing both growth outcomes and feed utilisation efficiency.

Keywords: Indian major carps, Polyculture system, *Labeo catla*, *Labeo rohita*, *Cirrhinus mrigala*

1. INTRODUCTION

Global food security, nutrition, and livelihoods are greatly enhanced by fisheries and aquaculture, especially in areas where aquatic resources are essential. With the capacity to meet the growing demand for fish and the ability to efficiently utilize aquatic habitats, aquaculture is now the most important food production industry with the highest rate of growth (Dhala et al., 2023). Inland fisheries produce over 75% of India's total fish production, ranking it third in the world for fish production and second for aquaculture (Handbook on Fisheries Statistics, 2023). Freshwater aquaculture is dominated by Indian main carps, such as catla, rohu, and mrigal, because of their market demand, adaptability and ease of breeding. Aquaculture, especially in underdeveloped nations, is an important strategy for enhancing food security, since it produces more efficiently on a comparatively smaller area of land or water than traditional agriculture (Dhala et al., 2023). Fish productivity and ecosystem health are improved by polyculture systems, which use several compatible species and have been shown to be more environment friendly and productive than monoculture (Prakash et al., 2018). Further, the most common method of fish production in India is carp polyculture, which includes the use of manures/fertilisers and supplementary feeding to achieve economical production, thereby supporting higher stocking densities and better fish growth performance. Since, supplementary feed accounts for 50-60 of production costs, effective feed management is essential (Sharma et al., 2022). Growth performance, feed utilisation, disease resistance, and overall

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profitability can all be greatly enhanced by optimising the feeding schedule (feed types, forms, rates, and frequency), which significantly impacts fish growth, survival, feed utilisation efficiency, and the economics of the entire production process. To maximize output and reduce environmental effects, the present study addresses how feeding management influences ecosystem balance, nutrient dynamics, and sustainable productivity in semi-intensive carp polyculture systems. It is important to develop an ideal feeding strategy for the species based on its nutritional needs and culture conditions. Although previous studies have explored various aspects of feeding strategies in carps (Das et al., 2000; Sultana et al., 2001; Abid & Ahmed, 2009; Baruah et al., 2020; Das et al., 2021), a limited comprehensive literature is available on the complete package of practices for the feeding regime for the rearing of carps under a semi-intensive polyculture system. With this background, the present study was undertaken to assess how different feeding regimes, such as feed types, feeding rates, and feeding frequencies, will affect the survival, growth, and productivity of Indian major carps produced in semi-intensive carp polyculture.

2. MATERIALS AND METHODS

2.1. Experimental Design

The experiment was conducted for 120 days at the College of Fisheries, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, in outdoor cemented tanks (80 m^2) with five treatments (FR1/C to FR5) by following a completely randomised design (Table 1).

2.2/ Preparation of Experimental Feed

Both dough and pelleted feed were prepared using locally available ingredients, viz. rice bran (49%), mustard meal (49%), fish-specific mineral mixture prepared by Guru Angad Dev Veterinary and Animal Sciences University (1.5%) and common salt (0.5%) (Kumar et al., 2019). Dough feed was prepared daily, whereas pelleted feeds were prepared by thoroughly mixing all ingredients and using a mechanical pelletizer, then stored in an airtight container for use during the experimental period.

2.3. Proximate Analysis of Feed Ingredients and Experimental Feed

The proximate analysis (% DM basis) with respect to crude protein (CP), crude fibre (CF), Ether extract (EE), ash, moisture and nitrogen free extract (NFE) of different feed ingredients and experimental feed (Table 2) was done, by following the standard methods of (AOAC, 2005).

2.4. Preparation of Experimental Tanks

All the experimental tanks were cleaned, dried and layered with a 4-inch soil layer. Liming was carried out by using limestone ($CaCO_3$) @ 250kg ha^{-1}. The water depth was maintained at 105±5.0 cm. Experimental tanks were manured with farmyard manure @ 5,000 kg ha^{-1} (40 kg $tank^{-1}$) a fortnight before fish stocking of fish, and then @ 1,250 kg ha^{-1} (10 kg $tank^{-1}$) at monthly intervals to maintain nutrient availability and plankton production. The experimental tanks were maintained for 15 days after initial manuring.

2.5. Stocking of Fish

Fish fingerlings were stocked @ stocking ratio of 3:4:3 [Surface (SF): column (CF): bottom feeder (BF)] in all the treatment groups @ 80 fish fingerlings $tank^{-1}$ (10,000 fish fingerlings ha^{-1}), after proper acclimatisation.

2.6. Feeding of Fish

Fish were fed with dough and pelleted supplemental feeds. The amount of feed was adjusted after each monthly

Table 1. Treatments with respect to feeding regimes

Treatments	FR1/C	FR2	FR3	FR4	FR5
Feed form*	D1	D2	D2	D2	D2
Feeding rate (% BW)	2%	2%	2%	3%	3%
Feeding frequency day^{-1}	Twice	Twice	Thrice	Twice	Thrice

****Feed D1: Dough feed, Feed D2: Pelleted feed***

Table 2. Proximate composition of feed ingredients and experimental feeds (on % dry matter basis)

Ingredients/ experimental diets	Crude protein (%)	Ether extract (%)	Crude fiber (%)	Ash (%)	Nitrogen free extract (%)
Rice bran*	12.24	1.44	15.06	11.19	60.05
Mustard meal*	38.69	2.60	14.80	8.10	35.80
Dough & pelleted feed	27.24	1.52	17.53	10.92	42.78

****deoiled***

sampling in accordance with the increase in the weight of the fish.

2.7. Water Quality Parameters

Water quality parameters, i.e., Temperature, pH, Dissolved oxygen (DO), Total alkalinity (TA), Total hardness (TH), Ammonical-nitrogen (NH_3-N), Nitrate-nitrogen (NO_3-N) and Orthophosphate, were analysed monthly as per standard procedures of APHA (2012).

2.8. Fish Survival and Growth

Fish growth was studied at monthly intervals in terms of total length gain (TLG), net weight gain (NWG), net fish biomass production (g $tank^{-1}$), specific growth rate (SGR), condition factor (K), feed conversion ratio (FCR) and survival (%) were calculated after the completion of experiment.

2.9. Blood Metabolic Profile and Haematological Parameters

The blood metabolic profile parameters, i.e., glucose, alanine aminotransferase (ALT) and aspartate aminotransferase (AST). However, the haematological parameters, i.e., total erythrocyte Count (TEC)/ total red blood cell count (RBC), total leukocyte count (TLC)/ total white blood cell Count (WBCs), haemoglobin (Hb) and haematocrit value or packed cell volume (PCV) were recorded at the termination of the experiment.

2.10. Statistical Analysis

The statistical package (SPSS 16.0 for Windows, SPS Inc., Richmond, CA, USA) was used for statistical analysis of the data. The data were statistically analysed using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) to establish the influence of feeding regimes on water quality, fish survival, growth, biochemical and haematological parameters with respect to significant difference ($p<0.05$) among the treatment group means. Data are presented as mean ± standard error (SE).

3. RESULTS AND DISCUSSION

3.1. Water Quality

The water quality parameters range viz. water temperature pH, Dissolved oxygen (DO), total hardness (TH), total alkalinity (TA), NH_3-N, NO_3-N, Ortho-Phosphate was 14.36 to 26.93°C, 7.33 to 8.40, 8.00 to 9.66 mg L^{-1}, 151.33 to 235.33 $CaCO_3$ mg L^{-1}, 140.00 to 214.00 $CaCO_3$ mg L^{-1}, 0.035 to 0.051 mg L^{-1}, 0.200 to 0.495 mg L^{-1} and 0.005 to 0.017 mg L^{-1} (Table 3). Water quality was not impacted by feeding fish with varying feeding schedules. Feeding frequency and rate are essential elements in semi-intensive fish culture for improved growth and increased yield. Increased feeding frequency may lead to increased growth and production rate. The water quality parameters remained within the suitable range for carps culture and were in similar trend as demonstrated by different researchers with respect to the water temperature (Seetha & Chandran, 2020), pH (Bhatnagar & Devi 2019), Dissolved Oxygen (Boyd & Tucker, 1998), total alkalinity (Ayyappan et al., 2011; Bhatnagar & Devi 2019), total hardness (Ayyappan et al., 2011; Purnamawati, 2019), ammonia (Ayyappan et al., 2011), nitrate (Santhosh & Singh, 2007) and ortho-phosphate (Boyd & Tucker, 1998).

3.2, Fish Survival and Growth

Fish's ability to adapt to changes in the environment is essential to their survival (Koedijk et al., 2012). The highest species survival rate was 94.44, 90.28, and 89.58% for mrigal, catla and rohu, respectively. Overall, FR5 (fish fed

Table 3. Water quality parameters in different treatments

Parameters	FR1/C	FR2	FR3	FR4	FR5
Temperature (°C)	21.08^{bc}±0.12	21.52^{a}±0.05	21.32^{ab}±0.02	21.12^{bc}±0.01	20.96^{c}±0.15
pH	7.75^{a}±0.01	7.74^{a}±0.01	7.77^{a}±0.01	7.78^{a}±0.01	7.77^{a}±0.01
D.O (mg L^{-1})	8.49^{a}±0.17	8.83^{a}±0.25	8.77^{a}±0.24	8.07^{a}±0.11	9.12^{a}±0.17
Total alkalinity ($CaCO_3$ mg L^{-1})	175.73^{ab}±1.25	186.40^{a}±4.46	166.27^{ab}±1.25	159.33^{ab}±5.54	154.40^{b}±6.80
Total hardness ($CaCO_3$ mg L^{-1})	191.47^{a}±1.24	200.80^{a}±1.09	168.93^{a}±1.14	174.73^{a}±9.88	176.60^{a}±6.90
NH_3-N (mg L^{-1})	0.047^{a}±0.00	0.045^{a}±0.00	0.043^{a}±0.00	0.044^{a}±0.00	0.044^{a}±0.00
NO_3^--N (mg L^{-1})	0.286^{a}±0.03	0.311^{a}±0.01	0.270^{a}±0.05	0.263^{a}±0.01	0.259^{a}±0.01
Ortho-phosphate (mg L^{-1})	0.012^{a}±0.00	0.010^{ab}±0.00	0.010^{ab}±0.00	0.008^{b}±0.00	0.010^{ab}±0.00

Data are presented as mean ± SE; n=3

Mean values with different superscripts across the rows indicate significant differences (p<0.05), as assessed by one-way ANOVA and Duncan's multiple range test

FR1/C= D1, 2% & twice, FR2= D2, 2% & twice, FR3= D2, 2% & thrice, FR4= D2, 3% & twice and FR5= D2, 3% & thrice

with pelleted feed @ 3% BW & three times a day) recorded the highest average fish survival rate (91.43%), while FR1 recorded the lowest (83.56%) (Table 4). Garg and Kalla (2018) also reported that, with an increase in feeding frequency from one to four times a day, both survival rate and growth increased significantly in Indian major carps. These results suggest that a feeding frequency of thrice a day is sufficient for achieving better survival and optimal growth performance of Indian major carps under intensive culture conditions, as it ensures adequate nutrient availability throughout the day while minimising metabolic stress and maintaining stable water quality parameters.

Total length gain in catla (*Labeo catla*) ranged from 5.73 cm (FR1/C) to 8.71 cm (FR3), showing significant variation among treatments. Net weight gain ranged from 19.92 g (FR1/C) to 33.96 g (FR5), with significantly higher values in FR3–FR5 than in the control. The specific growth rate ranged from 1.87% (FR1/C) to 2.28% (FR5), showing a significant increase across treatments. The condition factor (K) ranged from 1.02 (FR3) to 1.52 (FR4 and FR5) with significant difference between FR1/C and FR3, but non-significant differences among FR2, FR4, and FR5. Net biomass production ranged from 360.51 g (FR1/C) to 730.27 g (FR5), with significantly higher yields in FR3–FR5 compared to FR1/C and FR2.

Total length gain in rohu (*Labeo rohita*) ranged from 6.14 cm (FR1/C and FR2) to 7.58 cm (FR5), showing significant variation among treatments. Net weight gain ranged from 16.63 g (FR1/C) to 24.70 g (FR5), with significant differences observed between FR1/C and FR3 and non-significant differences between FR4 and FR5. Specific growth rate ranged from 1.42% (FR1/C) to 1.67% (FR5), with significant differences among treatments. The condition factor (K) ranged from 1.03 (FR1/C) to 1.20 (FR4), with no significant differences among FR2, FR3, and FR4 but a significant difference between FR1/C and FR5 ($P \leq 0.05$). Net biomass production ranged from 437.23 g (FR1/C) to 695.17 g (FR5), with values significantly higher in FR3–FR5 than in FR1/C and FR2.

Total length gain in mrigal (*Cirrhinus mrigala*) ranged from 4.89 cm (FR1/C) to 6.13 cm (FR5), with significant differences among FR1/C–FR3 ($P \leq 0.05$) and non-significant differences between FR4 and FR5 ($P \leq 0.05$). Net weight gain ranged from 16.86 g (FR1/C) to 22.86 g (FR4), indicating significant differences among treatments. Specific growth rate ranged from 1.16% (FR1/C) to 1.35% (FR4), with significant differences among FR1/C, FR2, and FR3. The condition factor (K) ranged from 0.96 (FR5) to 1.07 (FR1/C) with non-significant differences among FR1/C, FR2, and FR3 but significant differences in FR4 and FR5. Net biomass production ranged from 290.67 g (FR1/C) to 501.37 g (FR4), with significant differences among treatments. The maximum net weight gain for mrigal was observed in FR4 (22.86 g), while for catla (33.96 g) and rohu (24.70 g) was in FR5 (Table 5).

The best growth performance observed with pelleted feed in the present study is consistent with the findings of Das et al. (2021), who reported better growth performance when fish were fed pelleted feed compared to dough feed. Garg and Kalla (2018) reported that higher feeding frequencies were associated with higher SGR in *Cirrhinus mrigala*. Aga et al. (2017) also observed higher SGR and body weight gain in rohu fed a supplementary diet at a 4% feeding rate twice daily. Sultana et al. (2001) also observed that common carp fry fed pelleted feed at a 5% feeding rate, four times/day, exhibited the best growth performance in terms of WG and SGR. Baruah et al. (2020) observed that feeding regimes with lower feeding rates (1% BW day^{-1})

Table 4. Survival (%) of fish in different treatments at the end of the experiment

Species	Treatments				
	FR1/C	FR2	FR3	FR4	FR5
Catla	80.55^{a}±3.67	87.50^{a}±6.36	86.11^{a}±5.00	88.89^{a}±1.39	90.28^{a}±1.39
Rohu	85.42^{a}±3.75	89.58^{a}±7.29	88.54^{a}±4.54	87.50^{a}±1.80	89.58^{a}±1.04
Mrigal	84.72^{a}±3.67	91.66^{a}±6.36	90.27^{a}±2.77	93.05^{a}±1.38	94.44^{a}±1.38
Average survival	83.56^{a}±3.33	89.58^{a}±6.59	88.31^{a}±4.06	89.81^{a}±1.02	91.43^{a}±0.70

See Table 3 for legends
(Data are presented as mean ± SE; n=3
Mean values with different superscripts across the rows indicate significant differences (p<0.05), as assessed by one-way ANOVA and Duncan's multiple range test.
FR1/C= D1, 2% & twice, FR2= D2, 2% & twice, FR3= D2, 2% & thrice, FR4= D2, 3% & twice and FR5= D2, 3% & thrice.)

resulted in poorer growth performance than feeding rates of 3% BW day^{-1} and 6% BW day^{-1}. Ahmed (2007) reported greater weight gain and SGR in rohu at feeding rates of 6-8% body weight. Khan (2004) reported increased daily body weight gain in mrigal when feeding rates increased from 2% to 6%. The direct relationship between feeding frequency and growth in *L. rohita* fingerlings was observed by Choudhury et al. (2002). Abid and Ahmed (2009) further support the findings of the present study. Das et al. (2000) observed a decrease in FCR with an increase in feeding frequency from once to twice per day for catla and rohu, which is in accordance with the present study, collectively suggesting that optimised feeding frequency and rate, along with feed form, are critical determinants of growth performance and feed utilisation efficiency in Indian major carps. At the end of the experiment, FCR and PER values ranged from 1.62 (FR3) to 2.68 (FR5) and from 1.39 (FR5) to 2.33 (FR2), respectively, indicating significant differences among the treatments (Table 4). However, FR2 (1.62 and 2.33) and FR3 (1.61 and 2.32) exhibited the highest FCR and PER values among the treatments.

The present study demonstrated improved growth performance with increasing feeding frequency, consistent with previous reports in carps. Abid and Ahmed (2009) observed that increasing feeding frequency from 1 to 3 times per day significantly increased final weight in rohu

Table 5. Growth parameters of catla (*L. catla*), rohu (*L. rohita*) and mrigal (*C. mrigala*)

Parameters	Treatments				
	FR1/C	FR2	FR3	FR4	FR5
Catla					
TLG (cm)	5.73^{c}±0.91	6.20^{c}±0.97	8.71^{a}±0.11	6.81^{b}±0.13	6.93^{b}±0.26
NWG (g)	19.92^{d}±0.26	25.93^{c}±0.23	32.90^{b}±0.30	32.90^{b}±0.15	33.96^{a}±0.23
SGR (%)	1.87^{d}±0.03	2.03^{c}±0.02	2.20^{b}±0.02	2.22^{ab}±0.00	2.28^{a}±0.01
Condition factor (K-value)	1.24^{b}±0.03	1.42^{a}±0.03	1.02^{c}±0.01	1.52^{a}±0.04	1.52^{a}±0.08
Net fish biomass production (g tank^{-1})	360.51^{c}±1.28	537.90^{b}±4.63	671.13^{a}±3.84	695.20^{a}±9.99	730.27^{a}±7.78
Rohu					
TLG (cm)	6.14^{c}±0.16	6.14^{c}±0.16	6.60^{b}±0.03	6.86^{b}±0.08	7.58^{a}±0.05
NWG (g)	16.63^{d}±0.16	19.60^{c}±0.05	21.96^{b}±0.24	24.36^{a}±0.14	24.70^{a}±0.32
SGR (%)	1.42^{d}±0.01	1.50^{c}±0.00	1.61^{b}±0.01	1.66^{a}±0.01	1.67^{a}±0.02
Condition factor (K-value)	1.03^{b} ±0.03	1.18^{a}±0.04	1.15^{a}±0.01	1.20^{a}±0.02	1.04^{b}±0.01
Net fish biomass production (g tank^{-1})	437.23^{c}±2.12	548.67^{b}±5.35	608.20^{ab}±3.02	667.00^{a}±1.90	695.17^{a}±6.25
Mrigal					
TLG (cm)	4.89^{b}±0.18	5.04^{b}±0.04	5.20^{b}±0.07	6.05^{a}±0.05	6.13^{a}±0.07
NWG (g)	16.86^{d}±1.00	17.93^{cd}±0.16	18.50^{c}±0.05	22.86^{a}±0.14	20.96^{b}±0.17
SGR (%)	1.16^{c}±0.03	1.19^{bc}±0.00	1.23^{b}±0.01	1.35^{a}±0.00	1.31^{a}±0.00
Condition factor (K-value)	1.07^{a}±0.01	1.06^{a}±0.00	1.06^{a}±0.00	1.03^{b}±0.00	0.96^{c}±0.01
Net fish biomass production (g tank^{-1})	290.67^{d}±54.52	317.57^{cd}±27.04	388.03^{bc}±16.09	501.37^{a}±1.03	468.00^{ab}±1.02
FCR	1.80^{bc}±0.18	1.62^{c}±0.20	1.61^{c}±0.18	2.45^{ab}±0.18	2.68^{a}±0.27
PER	2.08^{ab}±0.19	2.33^{a}±0.30	2.32^{a}±0.24	1.51^{b}±0.11	1.39^{b}±0.14
Total initial biomass (g tank^{-1})	308.00^{b}±0.46	317.33^{a}±2.82	309.60^{ab}±2.01	316.27^{a}±3.00	310.67^{ab}±2.2
Total final biomass (g tank^{-1})	1396.40^{c}±8.52	1721.50^{b}±1.27	1977.00^{a}±8.33	2179.80^{a}±2.67	2204.10^{a}±1.29
Net fish biomass (g tank^{-1})	1088.40^{c}±8.49 (10.88 Kg)	1404.10^{b}±1.24 (14.04 Kg)	1667.40^{a}±8.37 (16.67 Kg)	1863.60^{a}±2.87 (18.63 Kg)	1893.40^{a}±1.0 (18.93 Kg)

See Table 3 for legends
(Data are presented as mean ± SE; n=3
Mean values with different superscripts across the rows indicate significant differences (p<0.05), as assessed by one-way ANOVA and Duncan's multiple range test.
FR1/C= D1, 2% & twice, FR2= D2, 2% & twice, FR3= D2, 2% & thrice, FR4= D2, 3% & twice and FR5= D2, 3% & thrice.)

fingerlings, supporting the current findings. Similarly, Sultana et al. (2001) reported superior growth performance, including higher NWG, SGR, and PER, in common carp fry fed four times per day compared with lower frequencies. Das et al. (2000) found optimal growth and feed utilisation in catla and rohu fingerlings at twice-daily feeding, although they suggested three times feeding as adequate under intensive culture conditions. Honnananda et al. (2019) further confirmed that increased feeding rates improved survival, growth, SGR, and FCR in Indian major carps. However, Sultana et al. (2001) reported improved PER. They reduced FCR with higher feeding frequency, which contrasts with the present results and suggests that feed utilisation responses to feeding frequency may vary with species, developmental stage, feeding rate, and culture conditions. At the end of the experiment, net fish biomass ranged from 10.88 Kg (FR1/C) to 18.93 Kg (FR5), showing significant differences (P≤0.05) among treatments. FR3 (16.67 Kg) had the highest net biomass, followed by FR4 (18.63 Kg) and FR5 (18.93 Kg) (Table 5).

3.3. Biochemical Parameters

*Glucose level (*mg dL^{-1}) *of catla* ranged from 80.75 (FR1/C) to 99.86 (FR5), showing significant differences among treatments. Rohu ranged from 82.83 (FR1/C) to 95.39 (FR4), differences were nonsignificant, and *mrigal* ranged from 81.44 (FR1/C) to 90.42 (FR4), differences were not significant. *AST values* (U L^{-1}) *of catla* ranged from 130.68 (FR3) to 156.56 (FR5), *rohu* ranged from 103.30 (FR1/C) to 131.71 (FR4), and *mrigal* ranged from 97.05 (FR2) to 118.25 (FR4). Differences in AST were not significant across treatments for any species. *ALT values of catla* ranged from 17.88 (FR1/C) to 22.44 (FR4), with significant differences; rohu ranged from 22.16 (FR5) to 24.89 (FR2), with insignificant differences; and mrigal ranged from 20.17 (FR2) to 23.11 (FR5), with insignificant differences. Overall, glucose and ALT levels showed significant variation among treatments only in *catla*, whereas AST levels did not differ significantly across species (Table 6).

Fish growth is related to feed intake; higher feed intake results in greater weight gain, but excessive feeding increases the feed conversion ratio, water pollution, and other disorders (Zhang et al., 2019). Fish fed less frequently had lower glucose concentrations than fish fed regularly, suggesting that feeding schedules may affect carbohydrate metabolism of carbohydrates and lead to behavioural changes, such as compensatory feeding (Dametto et al., 2018). Fish blood glucose is an extremely sensitive indicator of environmental stress. Fish blood glucose is an extremely sensitive indicator of environmental stress. Nekoubin et al. (2013) found that grass carp fed pelleted meals with higher protein content (25% to 35%) at 5% body weight, three times

Table 6. Biochemical parameters of blood serum of different fish species

Parameters	Treatments				
	FR1/C	FR2	FR3	FR4	FR5
Catla					
Glucose (mg dL^{-1})	80.75^{c}±4.24	83.54^{bc}±1.23	89.76^{abc}±4.57	95.86^{ab}±3.14	99.86^{a}±4.95
Aspartate aminotransferase (AST) (U L^{-1})	154.58^{a}±5.36	133.63^{a}±1.44	130.68^{a}±1.76	147.86^{a}±2.50	156.56^{a}±2.44
Alanine aminotransferase (ALT) (U L^{-1})	17.88^{b}±0.31	21.99^{a}±0.44	20.97^{ab}±0.76	22.44^{a}±1.87	21.83^{a}±1.03
Rohu					
Glucose (mg dL^{-1})	82.83^{a}±9.55	83.14^{a}±7.96	93.14^{a}±5.77	95.39^{a}±12.54	93.05^{a}±28.46
Aspartate aminotransferase (AST) (U L^{-1})	103.30^{a}±7.31	126.34^{a}±1.47	121.93^{a}±2.00	131.71^{a}±2.15	120.62^{a}±5.56
Alanine aminotransferase (ALT) (U L^{-1})	23.15^{a}±1.49	24.89^{a}±3.06	24.88^{a}±2.22	23.68^{a}±2.11	22.16^{a}±1.50
Mrigal					
Glucose (mg dL^{-1})	81.44^{a}±4.39	86.17^{a}±0.99	82.47^{a}±1.80	90.42^{a}±11.35	84.07^{a}±12.95
Aspartate aminotransferase (AST) (U L^{-1})	110.04^{a}±1.44	97.05^{a}±0.76	110.03^{a}±8.14	118.25^{a}±2.43	108.78^{a}±1.62
Alanine aminotransferase (ALT) (U L^{-1})	21.52^{a}±0.78	20.17^{a}±0.90	20.45^{a}±0.60	22.45^{a}±1.42	23.11^{a}±3.26

See Table 3 for legends
(Data are presented as mean ± SE; n=3
Mean values with different superscripts across the rows indicate significant differences (p<0.05), as assessed by one-way ANOVA and Duncan's multiple range test.
FR1/C= D1, 2% & twice, FR2= D2, 2% & twice, FR3= D2, 2% & thrice, FR4= D2, 3% & twice and FR5= D2, 3% & thrice.)

Table 7. Biochemical parameters of blood serum of different fish species

Parameters	Treatments				
	FR1/C	FR2	FR3	FR4	FR5
Catla					
TLC ($\times10^3$mm^{-3})	$1.56^{b}\pm0.26$	$2.30^{a}\pm0.18$	$2.21^{a}\pm0.06$	$2.46^{a}\pm0.14$	$2.46^{a}\pm0.15$
TEC ($\times10^6$mm^{-3})	$1.56^{b}\pm0.21$	$2.06^{ab}\pm0.12$	$2.10^{ab}\pm0.07$	$1.97^{ab}\pm0.29$	$2.23^{a}\pm0.03$
Hb (g%)	$5.53^{a}\pm0.43$	$6.40^{a}\pm0.60$	$6.36^{a}\pm0.58$	$6.06^{a}\pm0.06$	$6.76^{a}\pm0.33$
PCV/Hct (%)	$22.83^{a}\pm2.03$	$25.73^{a}\pm0.83$	$27.16^{a}\pm1.05$	$23.10^{a}\pm1.68$	$25.63^{a}\pm0.29$
Rohu					
TLC ($\times10^3$mm^{-3})	$1.63^{a}\pm0.17$	$1.92^{a}\pm0.15$	$1.72^{a}\pm0.06$	$1.92^{a}\pm0.09$	$1.96^{a}\pm0.15$
TEC ($\times10^6$mm^{-3})	$1.70^{a}\pm0.30$	$1.35^{a}\pm0.15$	$1.52^{a}\pm0.20$	$1.75^{a}\pm0.16$	$1.67^{a}\pm0.23$
Hb (g %)	$5.26^{b}\pm0.43$	$6.80^{a}\pm0.37$	$6.86^{a}\pm0.49$	$6.23^{ab}\pm0.08$	$6.03^{ab}\pm0.23$
PCV/Hct (%)	$22.93^{a}\pm2.03$	$23.13^{a}\pm0.74$	$25.06^{a}\pm1.61$	$26.33^{a}\pm0.86$	$23.73^{a}\pm0.67$
Mrigal					
TLC ($\times10^3$mm^{-3})	$1.48^{a}\pm0.27$	$1.88^{a}\pm0.09$	$1.76^{a}\pm0.09$	$1.92^{a}\pm0.06$	$1.66^{a}\pm0.19$
TEC ($\times10^6$mm^{-3})	$1.19^{a}\pm0.01$	$1.53^{a}\pm0.22$	$1.43^{a}\pm0.13$	$1.82^{a}\pm0.03$	$1.62^{a}\pm0.42$
Hb (g%)	$5.56^{a}\pm0.18$	$6.26^{a}\pm0.63$	$6.56^{a}\pm0.16$	$5.83^{a}\pm0.23$	$6.90^{a}\pm0.75$
PCV/Hct (%)	$21.30^{a}\pm2.01$	$25.70^{a}\pm2.90$	$24.56^{a}\pm1.09$	$26.03^{a}\pm0.92$	$25.00^{a}\pm1.11$

See Table 3 for legends
(Data are presented as mean ± SE; n=3
Mean values with different superscripts across the rows indicate significant differences (p<0.05), as assessed by one-way ANOVA and Duncan's multiple range test.

a day, had higher glucose levels, consistent with the present study. Wu et al. (2021) observed that feeding more frequently (1–4 times per day) was associated with noticeably higher blood glucose levels. The glucose levels in catla, rohu, and mrigal increased in tandem with feeding frequency (2 to 3 times/day).

3.4. Haematological Parameters

The minimum TLC was observed in FR1/C, while the maximum was in FR4 (catla and mrigal) and FR5 (rohu). Significant differences were observed only between the control (FR1/C) and treatments in catla, whereas differences were non-significant in rohu and mrigal across all treatments. The minimum TEC was observed in FR1/C and FR2, while the maximum was in FR5 (*catla*) and FR4 (*rohu* and *mrigal*). Significant differences were observed among treatments for *catla*, whereas differences were non-significant for *rohu* and *mrigal*. The minimum Hb concentration was consistently observed in the control (FR1/C) across all species, whereas the maximum was observed in FR5 (c*atla* and *mrigal*) and FR3 (*rohu*). Significant differences were observed among treatments for *rohu*, whereas differences were non-significant for *catla* and *mrigal*. The minimum haematocrit was recorded in the control (FR1/C) for all species, while the maximum was recorded in FR3 (*catla*) and FR4 (*rohu* and *mrigal*). Differences among treatments were insignificant for all three species (Table 7). Fish health and physiological status can be evaluated using haematology as a major indicator (Silva & Chamul, 2000; Fazio et al., 2019). Nekoubin et al. (2013) observed that grass carp fed pelleted diets at 5% BW with thrice-daily feeding had haematocrit values and RBC counts comparable to those of the present study.

CONCLUSION

The overall results demonstrate that the feeding regime significantly influences the survival, growth, and production performance of Indian major carps under semi-intensive polyculture. Although higher feeding rates and frequencies enhanced survival and individual growth. However, administration of pelleted feed at 2% body weight, three times per day, results in the best balance between growth, feed utilisation, and biomass production with improved feed conversion and protein efficiency, coupled with high net yield, indicating the most efficient and economically viable feeding strategy for sustainable carp polyculture systems.

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CRediT authorship contribution statement

Rubalpreet Kaur: Conducted the experiment, Analysed the data, Software, and wrote the original draft. **Khushvir Singh:** Conceptualisation, Supervision, Data curation, Critical evaluation of data, Writing - review & editing.**Amit Mandal:** Reviewing and editing. **Chanchal Singh:** Formal analysis, Reviewing and editing. **Abhishek Srivastava:** Reviewing and editing. **Jaspal Singh Hundal:** Data curation, Reviewing and editing

Conflict of Interest

The authors declared that they have no conflicts of interest among themselves or with the institute conducting the experiment.

Data Availability Statement

Data will be made available on request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the author(s) have not used an AI tool.

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