Indian J. Fish., 73 (3): 84-91, 2026 doi:10.21077/ijf.2026.73.3.173885-09

Available online at: epubs.icar.org.in/index.php/IJF

Comparative growth performance of Asian stinging catfish *Heteropneustes fossilis* (Bloch, 1794) under monoculture and polyculture systems

Chandrabhushan S. Nishad[1,2], Aditya Kumar[1*], Raghvendra Singh[1], Monika Gupta[1], Achal Singh[1] and Uttam Kumar Sarkar[1]

[1]ICAR-National Bureau of Fish Genetic Resources, Canal Ring Road, P. O., Dilkusha, Lucknow-226 002, Uttar Pradesh, India
[2]Kerala University of Fisheries and Ocean Studies (KUFOS), Panangad P. O., Kochi-682 506, Kerala, India

Abstract

The present study evaluated the growth performance and production potential of integrating Asian stinging catfish, *Heteropneustes fossilis* (Bloch, 1974) into Indian major carp (IMC) polyculture systems through partial and complete replacement of mrigal (*Cirrhinus mrigala*) in polyethylene lined ponds. The experiment was conducted for six months (October 2023–March 2024) in twelve polyethylene-lined earthen ponds (6 m×5 m×1 m). Four treatments were tested in triplicate: Control (catla + rohu + mrigal), T1 (50% mrigal replacement with singhi), T2 (100% mrigal replacement with singhi), and T3 (singhi monoculture). The average initial weights of catla, rohu, mrigal, and singhi were 24.10±0.65 g, 22.92±0.71 g, 16.14±0.58 g, and 9.02±0.44 g, respectively. Water quality parameters including temperature, pH, dissolved oxygen, total hardness, total alkalinity, ammonia-N, nitrite-N, and nitrate-N were monitored monthly and remained within acceptable ranges throughout the experimental period, with no significant differences among treatments except for nitrite-N levels. Total plankton abundance was adequate in all ponds which supported fish growth. Growth performance was evaluated through harvested weight, weight gain, percentage weight gain, specific growth rate (SGR), feed conversion ratio (FCR), survival, and biomass production. Catla exhibited the highest growth performance, attaining a harvest weight of 235.21±12.08 g in T2. Rohu and mrigal recorded superior growth in T1 compared to the control. Singhi achieved significantly better growth (1.63±0.50; 2.93±0.03) and survival (92 and 82%) in polyculture treatments as compared to monoculture. Total biomass production was significantly higher in T1 (6.92±0.75) and T2 (6.29±0.67) than in the control (4.23±0.50), while FCR values remained comparable among treatments.

*Correspondence e-mail:
aditya7884@gmail.com

Keywords:
Biomass production, *Cirrhinus mrigala*, Feed conversion ratio (FCR), Indian major carps, Plankton abundance, Specific growth rate (SGR)

Received : 05.12.2025
Accepted : 16.08.2026

Introduction

Aquaculture is an important economic activity in India and a rapidly growing sector, utilising diverse natural resources and offering potential for the culture of a wide range of species. Inland fish production has shown impressive growth, with an average annual increase of 8.18% in 2022–23, reaching a total production of 18.4 million t. Three species of Indian major carps, catla (*Labeo catla* Ham.), rohu (*Labeo rohita* Ham.) and mrigal (*Cirrhinus mrigala* Ham.) have been the key species for the freshwater aquaculture in India and contributes 61% of the total aquaculture production (Kumar *et al*., 2018a). In addition to native carps, Indian freshwater aquaculture includes three exotic species: silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), and common carp (*Cyprinus carpio*), which together make up approximately 9.5% of inland production (Kumar *et al*., 2018a). Although carps are widely cultivated, they are considered low-value species, which can limit profitability and reduce income for farmers. In recent years, there has been a shift toward cultivating high-value and more commercially viable species, alongside efforts to promote important indigenous varieties. These developments have not only boosted overall production (Das and Mishra, 2016) but also

enhanced species diversity for both producers and consumers. To further increase yields and improve farmers' incomes, initiatives are underway to introduce additional indigenous species into the aquaculture system as part of ongoing diversification strategies.

Heteropneustes fossilis (Bloch, 1794), commonly known as the stinging catfish or singhi, belongs to the family Heteropneustidae and the order Siluriformes. This indigenous catfish is commercially important in Asian aquaculture, especially in countries such as India, Thailand, Bangladesh, Pakistan, Nepal, Sri Lanka, Myanmar, Indonesia, and Cambodia (Akand *et al*., 1991; Burgess, 1989; Hossain *et al*., 2015). The fish is valued for its tender flesh, pleasant taste, and low-fat content, and it also holds significance in traditional medicine. Notably, *H. fossilis* has a high iron concentration (226 mg per 100 g), surpassing many other freshwater species (Chakraborty and Nur, 2012). Because of its nutritional value, it is recommended as a dietary supplement for anaemic patients (Kohli and Goswami, 1989; Alok *et al*., 1993). All these characteristics lead to its high market demand and economic value, typically ranging from US$6 to 8 per kilogram (Kumar *et al*., 2018b). Due to its ability to thrive in adverse ecological conditions such as oxygen depleted waters, high stocking densities, and its adaptability to pelleted feed, *H. fossilis* is considered a promising candidate for diversifying freshwater aquaculture in India (Tharakan and Joy, 1996; Kutty, 2001). Singhi generally has a much higher market price than mrigal, making it attractive for farmers seeking greater profitability. Therefore, the current study aims to evaluate the growth performance and production potential of *H. fossilis* in carp polyculture, specifically through partial and full replacement of mrigal in poly-lined ponds.

Materials and methods

The experiment was conducted over a six-month period, from October 2023 to March 2024, at the Live Fish Germplasm Resource Centre of the ICAR-National Bureau of Fish Genetic Resources (ICAR-NBFGR), Lucknow, India. Twelve polyethylene (PE)-lined earthen ponds, each measuring 6 m×5 m×1 m, were utilised for the study. Each pond was initially prepared by spreading a 15-20 cm layer of soil at the bottom. To enhance the buffering capacity of culture system, water was limed with calcium carbonate applied at a rate of 1000 kg ha^{-1}. Two days after liming, the ponds were filled with water and subsequently fertilised using raw cow dung at a rate of 3000 kg ha^{-1} (Boyd and Tucker, 2012). Fish stocking was carried out one week following fertilisation. The study evaluated the culture performance of Asian stinging catfish, in combination with Indian major carps (IMCs) *viz* catla, rohu, and mrigal under four different species combinations. The treatments were as follows: Control (T0) with catla (10 fish), rohu (10 fish), and mrigal (10 fish) in a 1:1:1 ratio; Treatment 1 (T1) with catla (10 fish), rohu (10 fish), mrigal (5 fish), and singhi (35 fish) in a 1:1:0.5:0.5 ratio; Treatment 2 (T2) with catla (10 fish), rohu (10 fish), and singhi (70 fish) in a 1:1:1 ratio; and Treatment 3 (T3) consisting of singhi monoculture with 210 fish. Each pond was stocked with 30 IMCs (stocking density of 1 fish m^{-2}) and 210 singhi (7 fish m^{-2}). The average initial weights of the stocked species were 24.10±0.65 g for catla, 22.92±0.71 g for rohu, 16.14±0.58 g for mrigal, and 9.02±0.44 g for singhi. Fish were fed twice daily to satiation with a commercial extruded floating pellet feed containing 32% crude protein. The quantity of feed provided to each pond was recorded daily throughout the experimental period. To maintain optimal water quality, 30% water exchange was carried out at 15 days intervals to remove uneaten feed and accumulated waste.

Water quality parameters

Water quality parameters, including temperature, pH, total dissolved solids, and dissolved oxygen, were monitored monthly using a multi-parameter probe (HI 9829, Hanna Instruments® Navi Mumbai, India). Total ammonium nitrogen, nitrite, and nitrate levels were measured using kits with a Hanna Multiparameter Photometer (HI83300). For statistical analysis, monthly observations from each pond were pooled and expressed as mean±SE over the experimental period.

Plankton quantification

The plankton samples for quantitative analysis were collected monthly between 08:00 and 09:00 hrs. Plankton abundance was estimated by collecting 20 l of water from four sites in each pond and filtering through a 70 µm plankton net to obtain a 50 ml sample, which was preserved in 5% buffered formalin. Plankton density was quantified using a Sedgwick-Rafter (S-R) cell under a stereo-zoom microscope (Leica S8 APO, Germany), counting plankton cells in six randomly selected squares and calculated using the following formula given by Welch (1948):

$$n = \frac{(a \times 1000) \times c}{l}$$

where,
n= No. of plankton per litre of water
a= Average no. of plankton in one small counting chamber of S-R cell
c= Volume of plankton concentrates (ml)
l=Volume of original water filtered (l)

Estimation of growth and survival

All the individuals from each pond and 50 fish from monoculture ponds were sampled at monthly intervals. Growth in terms of weight, weight gain, weight gain (%), specific growth rate (SGR), and food conversion ratio (FCR) were estimated (Kumar *et al*., 2018a). The following formulae were used for calculations:

Weight gain (mg) = Final weight (mg) - Initial weight (mg)

Weight gain (%) = [(Average final weight - Average initial weight) / Average initial weight] × 100

Specific growth rate (SGR, % day^{-1}) = ([ln (final weight (g)) - ln (initial weight (g))] / Duration of rearing period (days) × 100

$$\text{Apparent feed conversion ratio} = \frac{\text{Total weight of feed provided}}{\text{Net biomass gain}}$$

At the end of the experiment, fish were harvested by netting followed by complete draining of the ponds. Survival rates for each species were recorded and calculated using the following formula.

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

Statistical analysis of experimental data

All values were presented as means±SD and analysed by SPSS 25.0 software (SPSS Inc., Chicago, IL, USA). One-way analysis of variance (ANOVA) followed by *post-hoc* Duncan's tests were applied to determine significant differences between means. All analyses were performed at a significance level of 0.05.

Results and discussion

Water quality

Water quality parameters remained within acceptable ranges throughout the experimental period across all treatments (Table 1; Fig 1–3). No significant differences ($p>0.05$) were observed among treatments for temperature, pH, dissolved oxygen, total hardness, total alkalinity, total ammonia nitrogen, and nitrate nitrogen. However, nitrite-nitrogen concentration was significantly higher in T2 compared to the control and other treatments ($p<0.05$) (Fig. 2). Water quality parameters are critical for determining the growth and survival of fish in aquaculture systems (Brett, 1979). Effective management of these parameters is therefore essential for successful fish farming. In the present study, all measured water quality parameters remained within the recommended limits for aquaculture, with no significant differences observed between the treatments. Water temperature ranged from 19.2 to 27.8°C, with an average of 22.7°C. Similarly, previous studies have reported that lower water temperatures during winter are less favourable for fish growth, resulting in reduced growth performance (Debnath *et al*., 2016; Debnath and Sahoo, 2023). In the present study, however, water temperature remained similar across all experimental groups and therefore was unlikely to influence the comparative differences observed among treatments. Nevertheless, the overall growth rates

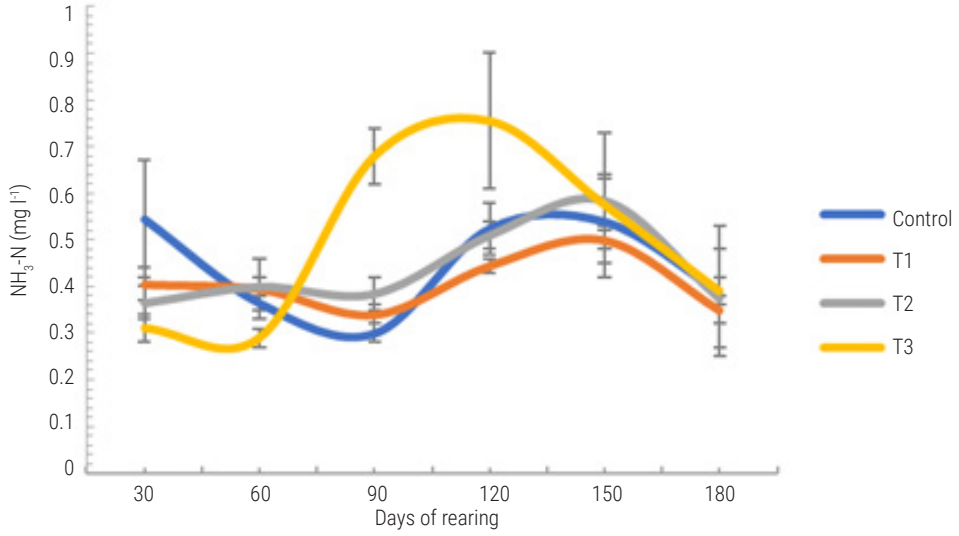

Fig. 1. Level of NH_3-N in the experimental ponds under different treatments during culture period

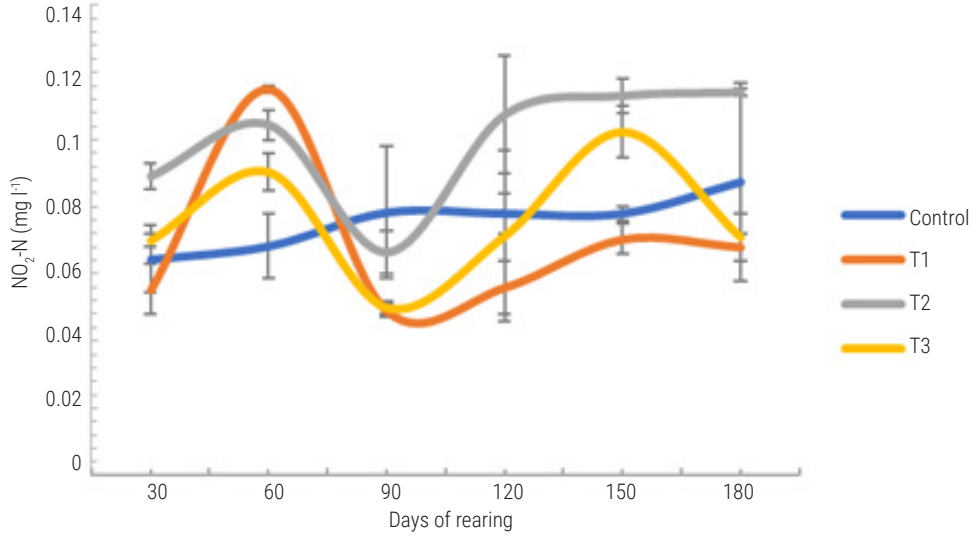

Fig. 2. Level of NO_2-N in the experimental ponds under different treatments during culture period

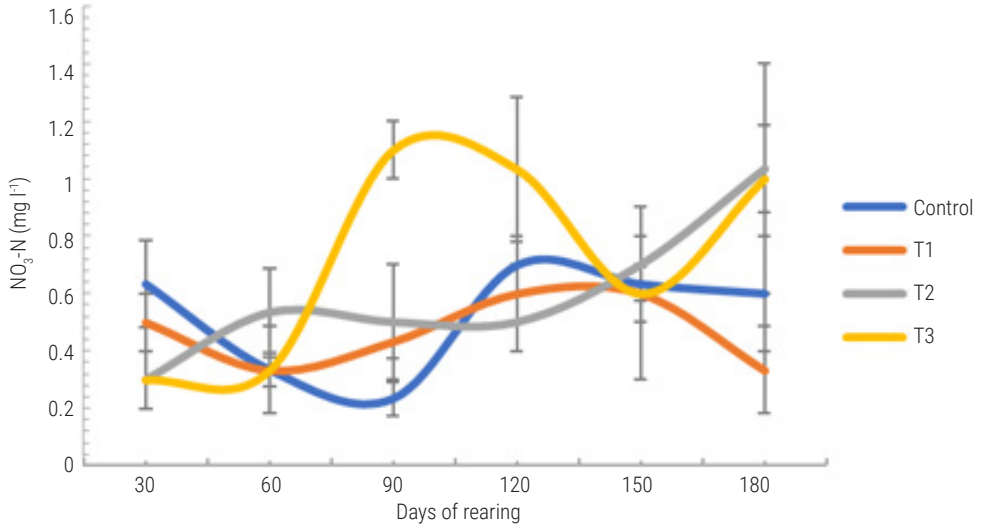

Fig. 3. Level of NO_3-N in the experimental ponds under different treatments during culture period

Table 1. Water quality parameters recorded during the experiment period

Parameters	Control	T1	T2	T3
Temperature (°C)	22.77±0.007[a] (27.85-18.75)	22.78±0.008[a] (27.21-19.26)	22.72±0.04[a] (27.05-19.23)	22.76±0.002[a] (7.81-19.6)
pH	7.6±0.23[a] (7.4-8.1)	7.6±0.17[a] (7.3-8.0)	7.6±0.32[a] (7.3-8.0)	7.6±0.25[a] (7.4-8.0)
Dissolved oxygen (mg l^{-1})	4.26±0.03[a] (3.98-4.67)	4.31±0.05[a] (3.83-4.74)	4.16±0.02[a] (3.76-4.62)	4.28±0.04[a] (3.71-4.55)
Total hardness (mg as $CaCO_3$ l^{-1})	240±30[a] (210-270)	230±40[a] (210-270)	240±30[a] (220-280)	220±30[a] (210-260)
Total alkalinity (mg as $CaCO_3$ l^{-1})	62±6.74[a] (43-82)	56±5.48[a] (44-79)	47±7.23[a] (39-62)	53±6.25[a] (46-78)

Values presented as mean±SE; Mean values in the same column with different superscript (a, b) differ significantly ($p<0.05$)

of the cultured species may have been compromised to some extent due to the prevailing low winter temperatures. It has been observed that higher temperatures are generally more favourable for fish growth. Dissolved oxygen and pH levels remained stable, likely due to regular liming and fertilisation carried out according to standardised carp grow-out management protocols. A slight increase in ammonia levels was noted, potentially resulting from a 'plankton die-off' associated with lower winter temperatures (Boyd and Tucker, 1992). However, ammonia concentrations remained within acceptable thresholds for fish culture. Total hardness was slightly elevated, which can be attributed to the use of underground water, but still fell within tolerable limits for carp polyculture, as reported by Jena *et al*. (2002); Sahu *et al*. (2007); Kumar *et al*. (2018a). Total alkalinity values, although comparatively low, remained within the acceptable range for carp polyculture as reported by Wurts (2002). Adequate alkalinity contributes to buffering capacity and stabilises pond pH fluctuations (Sahu *et al*., 2007). Maintaining water quality within optimal ranges supports healthy fish growth and survival, thereby enhancing the sustainability and productivity of aquaculture systems.

Plankton quantification

Quantitative analysis of plankton samples was conducted monthly between 08:00 and 09:00 hrs. The study monitored the growth of phytoplankton, zooplankton, and total plankton populations over a six-month culture period. Observed data under different treatments (Control, T1, T2, and T3) are presented in Fig. 4, 5 and 6. All treatments exhibited fluctuations in plankton populations throughout the study period. The plankton density available in ponds throughout the culture period indicated optimal availability of natural food for the fish (Sahu *et al*., 2007). The presence of higher levels of phytoplankton, in particular, was associated with increased productivity in the ponds. In the present study, phytoplankton density was observed consistently higher than zooplankton in all ponds which may be due to regular fertilisation and feeding practices, which promote phytoplankton growth. Keshavanath *et al*. (2002) emphasised that such practices are essential for maintaining high levels of phytoplankton, which in turn support the overall production of zooplankton which remained stable across treatments. The zoo-planktivorous nature of species like catla and singhi did not significantly impact zooplankton density. This finding aligns with the observations made by Parameswaran *et al*. (1971), who noted that certain fish species selectively feed on zooplankton without drastically reducing their populations. The rich plankton population observed in the ponds reflected the effective use of organic manure. The study's findings on the stable zooplankton density, despite the presence of zoo-planktivorous fish, suggest that effective plankton management can mitigate the potential impacts of fish feeding behaviours on plankton populations. There were no instances of blooming in the ponds, which indicates that the quantities of feed or fertilisers applied were either insufficient to adversely affect water quality or were well-adjusted within the pond ecosystem during the fish culture period. New (1987) discussed the importance of balancing feed and fertiliser application to prevent algal blooms,

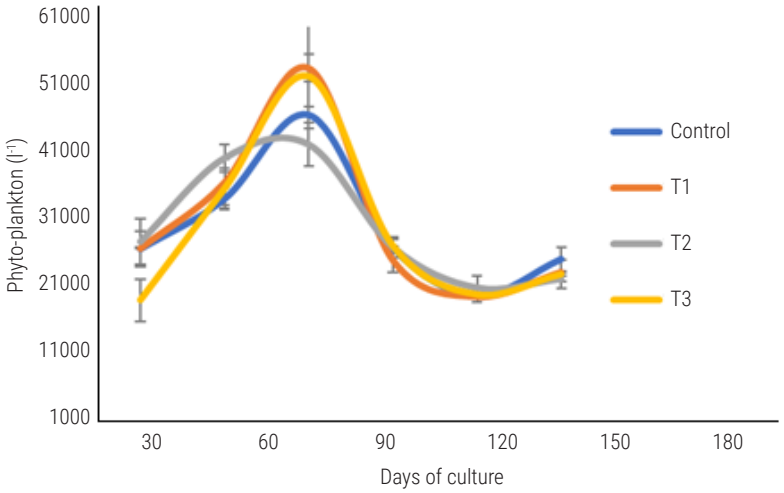

Fig. 4. Phytoplankton abundance in the experimental ponds under different treatments during culture period

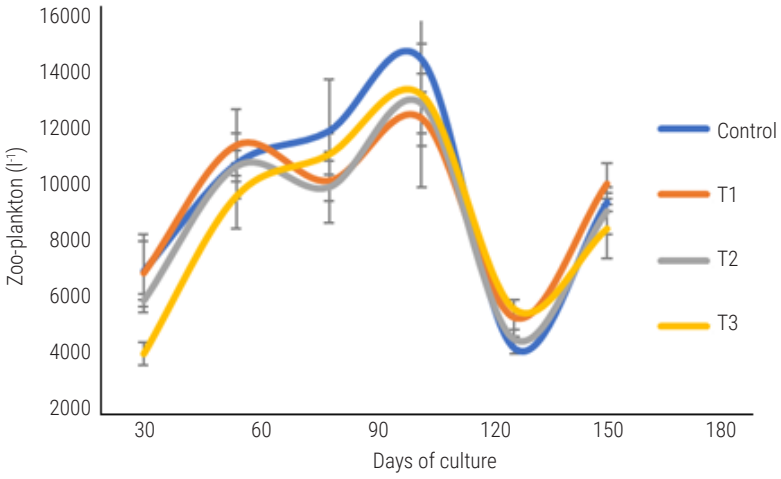

Fig. 5. Zooplankton abundance in the experimental ponds under different treatments during culture period

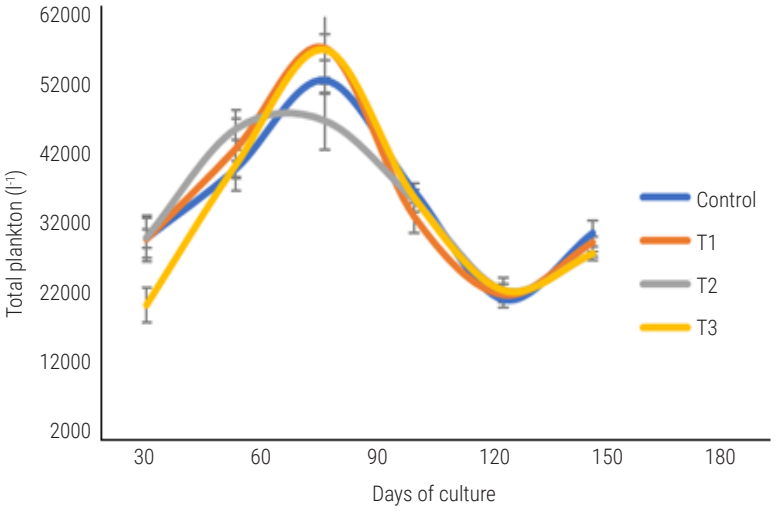

Fig. 6. Total plankton abundance in the experimental ponds under different treatments during the culture period

which can deplete oxygen levels and harm fish. The study's findings suggest that the management practices in place were effective in maintaining a balanced ecosystem.

Survival and growth

The recorded results including average harvested weight, net weight, net biomass, percentage weight gain, specific growth rate (SGR), and survival rate of different species in different treatments, are presented in Table 2. Singhi performed best under T1 polyculture conditions, achieving the highest harvested weight, net weight gain, SGR, and survival (95.24%). Growth and survival were lower in T2 and monoculture (T3). These findings indicate that polyculture conditions enhanced singhi performance compared to monoculture systems. Under monoculture of singhi, the total biomass was highest among all the treatments, though there was no significant difference observed among T1, T2, and T3 group. This is because the initial stocking biomass was higher in monoculture (in the tune of 2000 g, stocking rate 7 fish per m^2) of singhi. The inclusion of singhi in polyculture systems positively influenced the growth and production of catla (*L. catla*) and rohu (*L. rohita*). Catla recorded the highest growth, indicating a strong adaptability to polyculture conditions. Rohu also exhibited significant growth, suggesting that the integration of singhi did not negatively affect their performance. These results align with Kumar (1992), who emphasised the benefits of different feeding niche among these species. The differentiation in dietary habits of these species ensures that competition for food resources is minimised, allowing better overall productivity.

The specific growth rate (SGR) of singhi and other carps in this study was lower compared to previous findings (Jena and Das, 2011; Debnath *et al*., 2016; Rahman *et al*., 2016). This may be due to the lower temperatures during the study period as ectothermic organisms like fish experience reduced metabolic activity in colder conditions, leading to slower growth rates (Brett, 1979; Jobling, 1997; Hasan *et al*., 2021). The study recorded lower FCR values in polyculture treatments compared to monoculture (2.08±0.1), suggesting improved feed utilisation. Similar trends were reported by Debnath *et al*. (2020) in their study on Indian butter catfish (*Ompok bimaculatus*), where FCR values remained stable across treatments (indicating that species diversification does not negatively impact feed efficiency. Additionally, replacing singhi with mrigal resulted in improved production as also observed in the study by Debnath *et al*. (2020). The inclusion of singhi in polyculture systems likely contributed to an improved nutrient cycle within the pond environment. Haque *et al*. (2018) suggested that the presence of bottom-feeding species enhances organic matter breakdown, leading to increased plankton availability and better overall feed utilisation. This supports the idea that diversified polyculture systems contribute to sustainable aquaculture by enhancing resource efficiency (Thomas *et al*., 2021). The findings of this study highlight the importance of carefully selecting compatible species and managing feeding practices to optimise FCR and ensure sustainable production. Biomass production varied significantly among treatments (Table 2). The highest net biomass production was recorded in T3 followed by T1 and T2, whereas the lowest biomass production was observed in the control treatment. The higher biomass yield in treatments containing *H. fossilis* indicates that the co-culture of mrigal and singhi does not negatively impact their growth due to competition for food and living space, which aligns with their natural coexistence in the same ecological niche of the pond ecosystem. Present results support previous findings that species utilising different ecological niches can coexist efficiently in aquaculture systems (Parameswaran *et al*., 1971; Chandra and Haq,1986; Ahamed *et al*., 2017). Although individual

Table 2. Yield attributes of singhi and carps during the grow-out polyculture trial

Treatment	Species	Initial weight (g)	Harvested weight (g)	Net weight gain (g)	Net biomass (Kg)	% Weight gain	SGR	Survival %
Control	Catla	21.38±1.30	195.69±6.3^{a}	174.30±5.9^{a}	1.76±0.26^{a}	816.84±49.49^{a}	1.16±0.01^{b}	90.00±5.7^{a}
	Rohu	24.70±1.64	199.61±7.49^{a}	147.92±8.9^{a}	1.70±0.16^{a}	711.58±78.59^{a}	1.20±0.02^{a}	85.00±2.8^{a}
	Mrigal	17.15±1.52	118.12±3.45^{b}	100.96±4.53^{b}	0.77±0.08^{b}	591.67±52.94^{b}	1.10±0.01^{b}	65.00±2.8^{b}
	Singhi	-	-	-	-	-	-	-
Average/Total		21.07±3.52	171.14±40.14^{a}	150.06±37.27^{a}	4.23±0.50^{b}	706.70±111.25^{b}	1.15±0.04^{bc}	80.00±4.3^{a}
1	Catla	22.91±2.01	221.61±10.39^{a}	198.69±11.76^{a}	2.50±0.13^{a}	874.01±125.34^{a}	1.23±0.02^{a}	95.00±2.9^{ab}
	Rohu	23.71±0.79	207.27±9.60^{a}	183.55±10.17^{a}	2.12±0.17^{ab}	775.20±63.19^{ab}	1.22±0.02^{ab}	85.00±2.90^{b}
	Mrigal	17.91±2.48	131.90±2.70^{b}	113.98±0.69^{b}	0.67±0.04^{d}	644.92±94.89^{b}	1.16±0.01^{ab}	100.00±0.00^{a}
	Singhi	9.84±0.92	67.85±8.65^{c}	58.00±9.32^{c}	1.63±0.50^{c}	597.47±149.67^{b}	1.11±0.07^{c}	95.24±2.9^{ab}
Average/Total		18.60±5.95	157.15±64.94^{a}	138.55±57.43^{a}	6.92±0.75^{a}	722.90±149.05^{a}	1.18±0.05^{ab}	93.75±1.9^{b}
2	Catla	23.36±0.83	235.21±12.08^{a}	211.84±11.59^{a}	1.94±0.24^{b}	906.82±41.11^{a}	1.26 ± 0.02^{a}	85.00±2.9^{ab}
	Rohu	22.87±2.32	190.00±8.00^{b}	167.12±6.44^{b}	1.42±0.16^{c}	734.48±62.38^{ab}	1.17±0.02^{ab}	75.00±2.9^{b}
	Mrigal							
	Singhi	9.74±1.48	64.10±5.70^{c}	54.35±6.71^{c}	2.93±0.03^{a}	570.79±135.23^{b}	1.08±0.04^{c}	82.66±1.1^{a}
Average/Total		18.66±6.84	163.10±77.18^{a}	144.44±70.67^{a}	6.29±0.67^{a}	737.36±164.75^{a}	1.17±0.08^{a}	82.88±2.4^{a}
3	Catla	-	-	-	-	-	-	-
	Rohu	-	-	-	-	-	-	-
	Mrigal	-	-	-	-	-	-	-
	Singhi	9.85±0.92	56.93±0.65^{b}	47.09±1.47^{b}	7.85±0.61^{a}	482.06±62.26^{b}	1.02±0.01^{c}	86.90±4.8^{b}
Average/Total		9.85±0.92	56.93±0.65^{b}	47.09±1.47^{b}	7.85±0.61^{a}	482.06±62.26^{b}	1.02±0.01^{c}	86.90±4.8^{b}

Values presented as mean±SE; Mean values in the same column with different superscript (a, b) differ significantly (p<.05)

growth performance varied among species, the overall biomass yield increased with the inclusion of singhi, indicating improved resource utilisation and enhanced production efficiency within the polyculture system. The findings underscore the importance of selecting species with complementary feeding habits when designing polyculture systems for sustainable aquaculture.

This study demonstrates that integrating *H. fossilis* (singhi) into polyculture systems with IMCs (mrigal, catla, and rohu) can enhance overall growth and survival rates through efficient resource utilisation and niche differentiation. The grow-out study indicated that *H. fossilis* does not compete for the same feeding niches as IMC species, supporting the viability of co-culture systems. These findings highlight the potential of including singhi as a candidate fish species for sustainable and productive polyculture practices.

Acknowledgements

The authors express their sincere gratitude to the Director, ICAR-NBFGR, Lucknow, for his invaluable guidance and support throughout this study. We are also deeply thankful to all the staff members of the Fish Genetic Resource Centre of ICAR-NBFGR for their cooperation and assistance, which were crucial for the successful completion of this research. The financial support received from the CRP on Agrobiodiversity project, ICAR, New Delhi (EFC, 2021-2026) for carrying out the work is duly acknowledged.

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