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Dietary Chitosan as a Feed Additive: Effects on Growth Performance, Survival and Cannibalism in Striped Murrel (*Channa striata*) Fingerlings

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Abstract: Chitosan, a biodegradable polysaccharide derived from chitin, possesses various biomedical applications, making it a promising functional additive in aquafeeds. Dietary chitosan has been reported to enhance growth, nutrient utilization, stress tolerance, and disease resistance in various fish species, while potentially reducing aggressive behaviours such as cannibalism. The present study evaluated the effects of *Artemia*-derived chitosan on growth performance, survival, mortality, and cannibalism in striped murrel (*Channa striata*) fingerlings. Three diets were formulated: a basal diet, a basal diet supplemented with 5–10% chitosan, and a diet containing black soldier fly larvae (BSFL). The experiment was conducted over eight weeks under optimal water quality conditions, with proximate composition and physicochemical feed characteristics also assessed. Fingerlings fed the chitosan-based diet exhibited significantly increased final body weight, percentage weight gain, specific growth rate, and protein efficiency ratio, as well as a lower feed conversion ratio compared with other groups ($p < 0.05$). Enhanced feed stability and floatability in chitosan-based pellets contributed to improved utilization. Survival was highest, and cannibalism lowest, in the chitosan-fed group, indicating positive behavioural modulation. In contrast, the BSFL diet resulted in higher mortality and cannibalism, likely due to excessive lipid accumulation and deteriorated water quality. Overall, the findings highlight the potential of chitosan-based diets to promote sustainable growth in fish, particularly during the early developmental stages of murrel fingerlings.

Keywords: Cannibalism, Chitosan, Growth performance, Murrel fish, Fingerlings, Aquafeed

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Introduction

Murrels (*Channa striata*), commonly known as snakeheads, are highly esteemed freshwater fish in aquaculture due to their exceptional texture, flavour, and low-fat content. Their adaptability to diverse aquaculture systems has made them particularly prominent in India, where they hold significant cultural and economic importance (Sahu *et al*., 2012). However, wild populations of

Channa striata have been declining, largely due to habitat degradation caused by human activities (Muntaziana *et al.*, 2013), highlighting the need for sustainable aquaculture practices.

Murrels possess a specialized air-breathing organ that enables them to survive in low-oxygen environments, a trait that enhances their resilience in aquaculture settings. In addition to their nutritional value, murrels are recognized for their traditional medicinal applications in wound healing and are rich in essential amino acids, such as thromboxane and prostaglandin, making them an excellent protein source (Mohanty *et al.*, 2017). In commercial aquaculture, however, the seed supply often depends on capturing wild fry, which must then be trained to accept formulated diets.

Cannibalism presents a major challenge in rearing carnivorous fish species like *Channa striata*, particularly during early growth stages. This issue is often exacerbated by size variation, overcrowding, limited food resources, and suboptimal feeding strategies (Hecht and Pienaar, 1993; Kumari *et al.*, 2018).

Recent developments in fish feed formulation have increasingly focused not only on enhancing nutritional quality but also on incorporating functional ingredients with bioactive properties. Chitosan, a biodegradable and non-toxic polysaccharide derived from chitin, has attracted growing interest due to its broad spectrum of biological activities, including antibacterial, antifungal, antioxidant, and immunomodulatory effects (Iqbal *et al.*, 2023).

Dietary supplementation with chitosan has been shown to improve growth performance, enhance nutrient utilization, and increase disease resistance in a variety of aquaculture species (Iqbal *et al.*, 2023). Moreover, chitosan has demonstrated potential in reducing aggressive behaviours, including cannibalism particularly in carnivorous and territorial fish species by modulating stress responses and promoting more uniform growth (Zaki *et al.*, 2021).

Despite the high nutritional content of conventional aquafeeds, they often lack functional bioactive compounds that contribute to both physiological health and behavioural regulation. This limitation highlights a unsolved problem: the need for feed additives that support not only growth and immunity but also reduce stress-induced behaviours such as cannibalism. In this context, chitosan represents a promising multifunctional additive capable of enhancing the overall growth performance and health through its combined roles as a natural growth promoter, immunostimulant, and behavioural modulator (Zaki *et al.*, 2021; Iqbal *et al.*, 2023)

Brine Shrimp (*Artemia franciscana*) is a small crustacean that serves as a promising source of chitosan, which has a wide range of applications, including in aquaculture (Gharehaghaji *et al.*, 2020). The shells of *Artemia*, often discarded as waste, were utilized for chitosan extraction through chemical treatment. The extracted chitosan was subsequently used in the formulation of fish feed. *Artemia* not only serves as a sustainable ingredient for aquafeeds but also complements its role as a live feed for ornamental and freshwater fish fingerlings.

This study aims to assess the growth performance, survival rate, mortality, and cannibalism incidence in *Channa striata* fingerlings fed diets supplemented with *Artemia*-derived chitosan, in comparison to basal diets and diets containing Black Soldier Fly Larvae (BSFL).

Materials and Methods

Experimental setup

The experiment was conducted in three rectangular tanks, each with a capacity of 250 L, and covered with nylon mosquito nets to prevent contamination. Prior to stocking, the tanks were thoroughly cleaned, dried overnight, and rinsed again to ensure hygiene. Each tank was filled with 50 L of water and maintained consistently throughout the study. Seventy-five *Channa striata* fingerlings were stocked per tank. Water quality parameters such as aeration, temperature, pH, and total dissolved solids (TDS) were monitored and maintained using an aerator with an air stone, a temperature regulator, and a water quality kit. The fish were acclimated for 20 days on experimental diets before the actual study commenced. A 12:12 hour light-dark cycle was maintained, and feeding was carried out at 6% of body weight per tank (Kumari *et al.*, 2018).

Chitosan preparation

Chitosan was extracted from brine shrimp (*Artemia franciscana*) cyst shells, following the method described by Asem *et al*. (2010). The process involved three key steps: demineralization, deproteinization, and deacetylation.

Feed formulation

Fish feed as formulated using commercially available ingredients such as fish meal, soy flour, rice bran, wheat flour, maize flour, fish oil, and a vitamin-mineral premix. Gelatin and yeast (*Saccharomyces cerevisiae*) were included to produce floating pellets, with yeast also contributing additional protein. Three diets were formulated: (i) a basal diet, (ii) a basal diet supplemented with 5–10% chitosan, and (iii) a diet containing black soldier fly larvae (BSFL). All ingredients were carefully weighed and mixed; vitamins and minerals were added only after steaming the dough for 20 minutes to preserve their activity. The cooled dough was then pelletized, dried using hot air, and stored in airtight containers to maintain freshness.

Proximate analysis and physical properties of feed

Proximate analysis was performed to determine the levels of protein, lipid, carbohydrate, ash, and moisture content. Additionally, the physical properties of the feed such as floatability, bulk density, water stability, expansion ratio, and volume increase were evaluated using standard methods (Rawski *et al.*, 2020).

Measurement of feed

The dimensions of feed pellets (diameter and length; n = 10) were measured using a digital vernier caliper (Mitutoyo, Model 500-196-30, Japan). The surface area and volume of the pellets were subsequently calculated from the measured radius and height following the method described by Khater *et al*. (2014).

Moisture content

Ten feed pellets were randomly selected and weighed using an electronic digital balance. The moisture content was determined by drying the samples in a hot air oven at 105°C until a constant weight was achieved, following the method described by Khater *et al*. (2014):

$$\% \text{ of MC} = \text{Wet wt} - \text{dry wt} \ / \text{ wet wt} \times 100$$

Water stability (WS)

Water stability (WS) was determined as the percentage of feed mass remaining after immersion in water for 10 min, following the method of Umar *et al*. (2013), with modifications to simulate the feeding conditions of *Channa striata* fingerlings. For each diet, 100 g of feed sample was placed in a flask containing 500 ml of distilled water and agitated horizontally for 10 min. The mixture was then filtered through a 1 mm mesh strainer lined with filter paper, and the retained residues were dried at 50°C for 24 h to obtain the final dry weight. Each feed type was analyzed in ten replicates.

WS (%) = final sample weight − initial sample weight)/initial sample weight × 100

Floatability

For each diet, ten randomly selected pellets were placed in 250 ml beakers containing 200 ml of distilled water at room temperature. The test was conducted in triplicate, and the average number of pellets remaining afloat after 20 min was recorded, following the method described by Umar *et al*. (2013)

Floatability = Number of floating pellets after 20 min/ the total number of pellets introduced in the water × 100 Water stability (WS)

VI (Increase in Volume)

A 25 ml portion of feed (initial volume) was placed in a volumetric flask containing 100 ml of water. After 10 min, the final volume of the feed was recorded, and the expansion in water was calculated following the method of Rawski *et al*. (2020).

VI (%) = ((final volume − initial volume)/initial volume) × 100

Growth performance

The growth performance of *Channa striata* fingerlings was assessed by measuring significant parameters including final body weight (FBW), body weight gain (PWG), percentage of Body weight gain (PWG), feed conversion ratio (FCR), specific growth rate (SGR), protein efficiency ratio (PER), survival rate, mortality rate, and cannibalism rate (Ahmed *et al*., 2021; Hoseinifar *et al*., 2022).

Survival rate

The survival rate of the fish was calculated based on the number of individuals that survived at the end of the experiment relative to the number initially stocked.

Survival rate (%) = No. of larvae harvested/No. of larvae stocked 100

Mortality rate

Mortality rate was estimated as the proportion of fish that died during the experiment relative to the total number of fish stocked

Mortality rate = No. of dead fishes /No. of fishes stocked ×100

Final body weight

The final body weight was determined by dividing the total biomass of fish harvested from each tank by the total number of surviving fish in that tank:

FBW (g) = fish biomass in the tank (g)/number of fish in the tank

Body weight gain

Body weight gain was calculated as the difference between the final and initial mean body weights of the fish (n=3):

BWG (g) = final body weight (g)−initial body weight (g)

Specific growth rate

Specific growth rate was calculated to evaluate the daily growth performance of fish using the formula (n=3):

SGR (%/day) = (ln final body weight − ln initial body weight)/number of feeding days) × 100

Per cent of body weight gain

The percentage of body weight gain (PWG) was calculated using the formula (n=3):

PWG (%) = final body weight (g) − initial body weight (g)/initial body weight (g)) × 100

Feed Intake

Feed intake was determined as the difference between the total amount of feed offered and the uneaten feed recovered from each tank:

FI (g) = applied feed (g) − uneaten feed (g)

Feed conversion ratio

Feed conversion ratio was calculated to assess the efficiency with which feed was converted into body mass (n=3):

FCR = feed intake (g)/body weight gain (g)

Protein efficiency ratio

Protein efficiency ratio was determined to evaluate the efficiency of dietary protein utilization for growth (n=3):

PER = (body weight gain (g)/feed intake (g) × protein level in the diet (%)

Statistical analysis

All data are expressed as mean ± standard error (SE). The data were tested for normality and homogeneity of variances using the Shapiro–Wilk and Levene's tests, respectively. One-way analysis of variance (ANOVA) was then performed to identify significant differences ($p < 0.05$) among treatment groups. When significant differences were observed, Tukey's Honestly Significant Difference (HSD) post hoc test was applied to determine pairwise comparisons. All statistical analyses were carried out using SPSS software (version 26.0)

Results and Discussion

Growth performance studies were conducted on

Channa striata fingerlings over an eight-week period using three different dietary treatments: a basal diet, a basal diet supplemented with chitosan, and a diet incorporating black soldier fly larvae (BSFL). For each Various growth parameters were evaluated, including survival rate, mortality, and cannibalism, throughout the experimental period. The dietary chitosan-supplemented feed had a substantial impact on the growth performance of *Channa striata* fingerlings compared to the other dietary groups. The natural antibacterial, antioxidant, and immunostimulatory properties of chitosan likely contributed to enhanced sustainable growth and protection against major infections throughout the study period.

Physico chemical parameters of water

Water quality parameters were monitored throughout the experiment, as they play a critical role in the growth performance of *Channa striata* fingerlings. The parameters included temperature (26ºC to 29ºC), dissolved oxygen (6.4 to 8.2 $mg{\cdot}L^{-1}$), total dissolved solids (TDS; 380 to 404 $mg{\cdot}L^{-1}$), pH (7.3 to 8.4), and ammonia concentrations (>0.25 $mg{\cdot}L^{-1}$). All parameters were measured using standard water quality test kits and remained within the optimal range for the species throughout the experimental study.

Proximate analysis of feed

The proximate composition of the experimental diets was analyzed using standard methodologies (AOAC, 2019). The evaluation included both the basal diet supplemented with chitosan and the basal diet without chitosan. As shown in Table 1 and Figure 1, the proximate analysis revealed crude protein contents of 35% and 37%, crude lipid contents of 11% and 13%, crude carbohydrate levels of 23% and 27%, and ash contents of 8% and 7%, respectively. The BSFL-based diet exhibited a higher protein and lipid content, but lower carbohydrate levels, with moderate ash and moisture content. In contrast, both the chitosan-supplemented and standard basal diets demonstrated a more balanced nutritional profile, with moderate levels of protein, lipids, carbohydrates, and ash, making them suitable for sustainable growth in *Channa striata* fingerlings.

Physico-chemical parameters of experimental feed

The physico-chemical properties of the experimental diets were assessed following method of Rawski *et al*. (2020). The expansion ratio of Experimental Feeds 1 and 2 (29% and 28.5%) was slightly higher than that of Feed 3 (28.53%) (Table 2). Experimental Feed 1 also showed higher water stability (87.9%), floatability (92.1%), and volume increase (97.55%) compared to the other diets. The enhanced performance of Experimental feed 1 may be attributed to the presence of chitosan, which likely improved pellet integrity and functional characteristics. Higher water stability reduces nutrient depletion, supporting better feed efficiency and growth. Improved floatability ensures feed availability for surface-feeding fish like *Channa striata*, while greater expansion and volume gain reflect better processing quality and pellet structure. These results highlight the advantages of Experimental feed 1 in aquaculture, offering both nutritional balance and greater physical performance in aquatic conditions.

Growth parameters

Growth performance of *Channa striata* fingerlings was evaluated based on key parameters such as final body weight (FBW), body weight gain (BWG), percentage weight gain (PWG), feed intake (FI), specific growth rate (SGR), feed conversion ratio (FCR), and protein efficiency ratio (PER)(Fig. 2), following standard methodologies commonly applied in fish nutrition studies (Hosseini *et al*., 2022). The results demonstrated significant differences ($p<0.05$) among the three experimental groups, with the group receiving the chitosan-based diet (Exp 1) exhibiting superior growth performance compared to the other groups (Table 3).

Among the three groups, fingerlings in Exp 1 exhibited the highest growth performance, with a

Table 1: Proximate composition of the experimental diets

Parameter	Exp 1	Exp 2	Exp 3
Crude protein	38.5±1.5^{a}	37.0±2.0^{a}	38.0±1.0^{a}
Crude lipid	13.0±0.3^{a}	13.5±0.5^{a}	20.5±1.0^{b}
Carbohydrate	23.7±0.1^{b}	27.75±0.65^{a}	11.4±0.1^{c}
Moisture	5.1±0.6^{b}	5.7±0.1^{b}	11.4±0.1^{a}
Ash	7.85±0.35^{a}	6.85±0.05^{b}	5.6±0.3^{c}

Values are presented as mean ± SE (n = 3). Different superscripts within the same row indicate significant differences ($p < 0.05$).

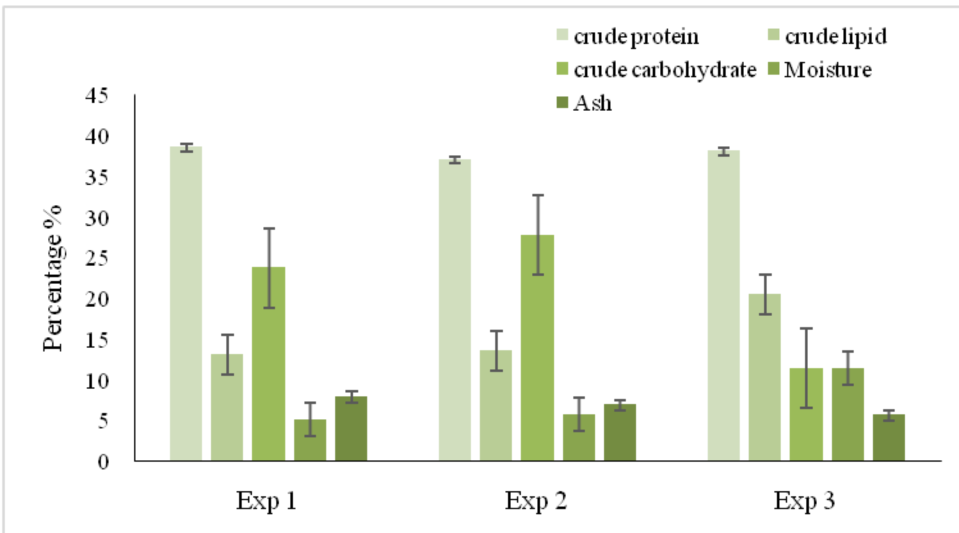

Fig. 1: Proximate composition (%) of experimental diets fed to *Channa striata* fingerlings in Exp 1 (chitosan-based diet), Exp 2 (basal diet), and Exp 3 (BSFL-based diet).

Table 2: Properties of feed analyzed using different parameters in experimental feed

Parameter	Exp 1	Exp 2	Exp 3
Pellet size (mm)	3.75±0.05^{b}	3.85±0.05^{a}	3.70±0.10^{c}
Water stability (%)	87.9±0.4^{a}	77.35±1.25^{c}	82.35±0.75^{b}
Floatability (%)	92.1±0.4^{b}	85.8±0.7^{c}	94.3±0.2^{a}
Volume increase (%)	97.55±1.05^{a}	93.0±0.5^{b}	91.55±1.05^{c}

Values are expressed as mean ± SE (n = 5). Different superscripts within rows indicate significant differences ($p < 0.05$).

Table 3: Growth performance of *C. striata* fingerlings

Feed type	FBW (g)	BWG (g)	PWG (%)	FI (g)	SGR (%/day)	FCR	PER
Exp 1	4.2±0.23^{a}	3.19±0.06^{b}	2.56 ± 0.12^{c}	4.2±0.23^{a}	3.19±0.06^{b}	2.56±0.11^{c}	4.2±0.23^{a}
Exp 2	2.89±0.24^{a}	1.83±0.06^{b}	1.20±0.08^{c}	2.89±0.24^{a}	1.83±0.06^{b}	1.20±0.07^{c}	2.89±0.24^{a}
Exp 3	90.0±5.13^{a}	57.4±6.31^{b}	37.4±2.41^{c}	90.0±5.13^{a}	57.4±6.31^{b}	37.4±2.85^{c}	90.0±5.13^{a}

Values are presented as mean ± SE (n = 3). Different superscripts in the same column indicate significant differences ($p < 0.05$). FBW =Final Body Weight, BWG = Body Weight Gain, PWG = Percentage of Body Weight Gain, FI = Feed Intake, SGR = Specific Growth Rate, FCR = Feed Conversion Ratio, PER = Protein Efficiency Ratio

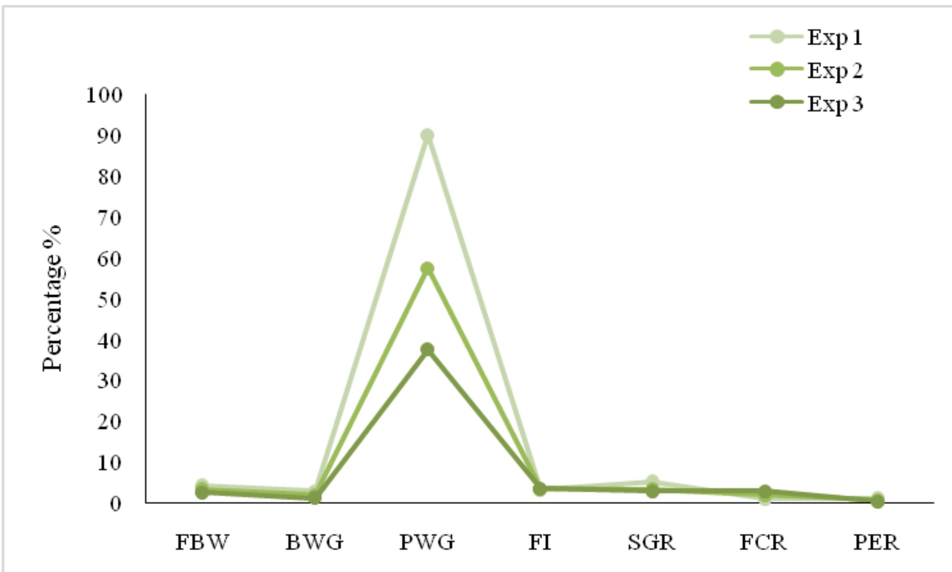

Fig. 2: Growth parameters of *Channa striata* fingerlings fed different diets: Exp 1 (chitosan-based diet), Exp 2 (basal diet), and Exp 3 (BSFL-based diet). FBW =Final Body Weight, BWG = Body Weight Gain, PWG = Percentage of Body Weight Gain, FI = Feed Intake, SGR = Specific Growth Rate, FCR = Feed Conversion Ratio, PER = Protein Efficiency Ratio.

final body weight of 4.2 ± 0.23 g, body weight gain of 2.89 ± 0.24 g, and percentage weight gain of 90 ± 5.13%. This significant improvement is likely attributable to enhanced nutrient absorption and utilization facilitated by the chitosan-supplemented diet. Although feed intake was slightly higher in Exp 2 (3.38 ± 0.01 g) and Exp 3 (3.40 ± 0.006 g), fish in Exp 1 consumed less feed (3.16 ± 0.04 g) yet achieved greater growth rate. These results indicate improved feed efficiency in the Exp 1 group, suggesting that dietary chitosan enhanced nutrient absorption and contributed to more effective biomass conversion.

Specific growth rate (SGR) was significantly higher in the Exp 1 group (5.17 ± 0.40%/day), compared to Exp 2 (3.27 ± 0.09%/day) and Exp 3 (2.84 ± 0.04%/day). The higher SGR observed in Exp 1 suggests enhanced physiological growth, potentially driven by the metabolic effects of chitosan. Previous studies have reported that chitosan can enhance digestive enzyme activity and improve nutrient absorption, which may contribute to improved growth performance in fish (Guzmán-Villanueva *et al*., 2014).

Feed conversion ratio (FCR) was optimal in the Exp 1 group (1.02 ± 0.03), suggesting more efficient conversion of feed into body mass. In contrast, the FCR values for Exp 2 and Exp 3 were significantly higher (1.84 ± 0.05 and 2.84 ± 0.04, respectively), indicating less efficient feed utilization. Protein efficiency ratio (PER) was also highest in Exp 1 (1.11 ± 0.09), while Exp 2 and Exp 3 recorded considerably lower values (0.64 ± 0.01 and 0.42 ± 0.005, respectively).

These results strongly support the efficacy of chitosan supplementation in promoting better growth rate in murrel fingerlings. The chitosan-based diet administered to the Exp 1 group probably offered a balanced nutritional composition along with functional properties such as antioxidative and antifungal activity. Linh *et al.* (2024) reported that these biological active compounds may have contributed to improved gut health and metabolic efficiency, thus enhancing nutrient assimilation and growth performance.

Furthermore, the low feed conversion ratio (FCR) observed in the Exp 1 group supports previous findings that chitosan can significantly enhance feed quality and utilization efficiency. Notably, the growth performance achieved in this study, particularly in terms of SGR and FCR, surpasses the results reported by Kumari *et al.* (2018). These results suggest that the chitosan-based diet formulated in the present study offers a more effective nutritional strategy for optimizing the aquaculture of *Channa striata*.

In summary, the inclusion of dietary chitosan derived from *Artemia* shells markedly improved growth parameters in *Channa striata* fingerlings. This improvement is most likely due to enhanced feed digestibility, improved protein utilization, and better overall metabolic health of the fish. These findings highlight the potential application of chitosan as a functional dietary additive in aquaculture to boost growth performance and feed efficiency.

Mortality, survival and cannibalism

Cannibalism and mortality rates were highest in the Exp 3 group of *Channa striata* fingerlings fed the black soldier fly larvae (BSFL)-based diet (Table 4). The BSFL a carnivore diet, while rich in protein and commonly used for carnivorous species, may have intensified post-feeding aggression and cannibalistic behaviour due to its high lipid content and stimulating effect on appetite (Baras and Jobling, 2002). In contrast, fingerlings in Exp 1, which received a chitosan-supplemented diet, exhibited significantly lower levels of aggression and cannibalism.

The lowest cannibalism rate (1.33 ± 0.08%) was observed in the chitosan-fed group (Exp 1), while the highest rate (4.2 ± 0.11%) occurred in the BSFL-fed group (Exp 3). Mortality, survival and cannibalism rate was monitored in weekly basis (Fig. 3). The reduced cannibalism in Exp 1 suggests that chitosan supplementation may help manage aggressive behaviour, likely through appetite regulation and stress reduction.

Mortality rates followed a similar pattern. Exp 3 showed the highest mortality (4.83 ± 1.17%), possibly due to the degradation of water quality caused by uneaten BSFL feed and lipid accumulation. BSFL feed is susceptible to spoilage and microbial growth after feeding, which can increase the risk of bacterial and fungal infections. In contrast, Exp 1 exhibited significantly lower mortality (3.0 ± 1.17%), likely due to the antimicrobial and antifungal properties of chitosan. This may have helped maintain better water quality and reduced the presence of harmful pathogens.

Channa striata fingerlings are highly vulnerable to microbial infections during early developmental stages. Therefore, nutritional diet along with bioactive compound that enhance immunity and improve environmental conditions. Chitosan, a natural compound derived from crustacean shells, is well-known for its antimicrobial and immune-boosting effects. Its presence in the feed likely prevented the growth of harmful microbes in the water, supporting better survival rates.

Table 4: Effect of different feeding diet on survival, mortality and cannibalism rate of *C. striata* fingerlings

Feed type	Survival rate (%)	Mortality rate (%)	Cannibalism rate (%)
Exp 1	91.0 ± 0.46^{a}	87.06 ± 0.46^{b}	85.75 ± 0.42^{c}
Exp 2	3.0 ± 1.17^{c}	4.43 ± 0.43^{b}	4.83 ± 1.17^{a}
Exp 3	1.33 ± 0.08^{c}	2.4 ± 0.06^{b}	4.2 ± 0.11^{a}

Values are presented as mean ± SE (n = 3). Different superscripts within the same column indicate significant differences ($p < 0.05$)

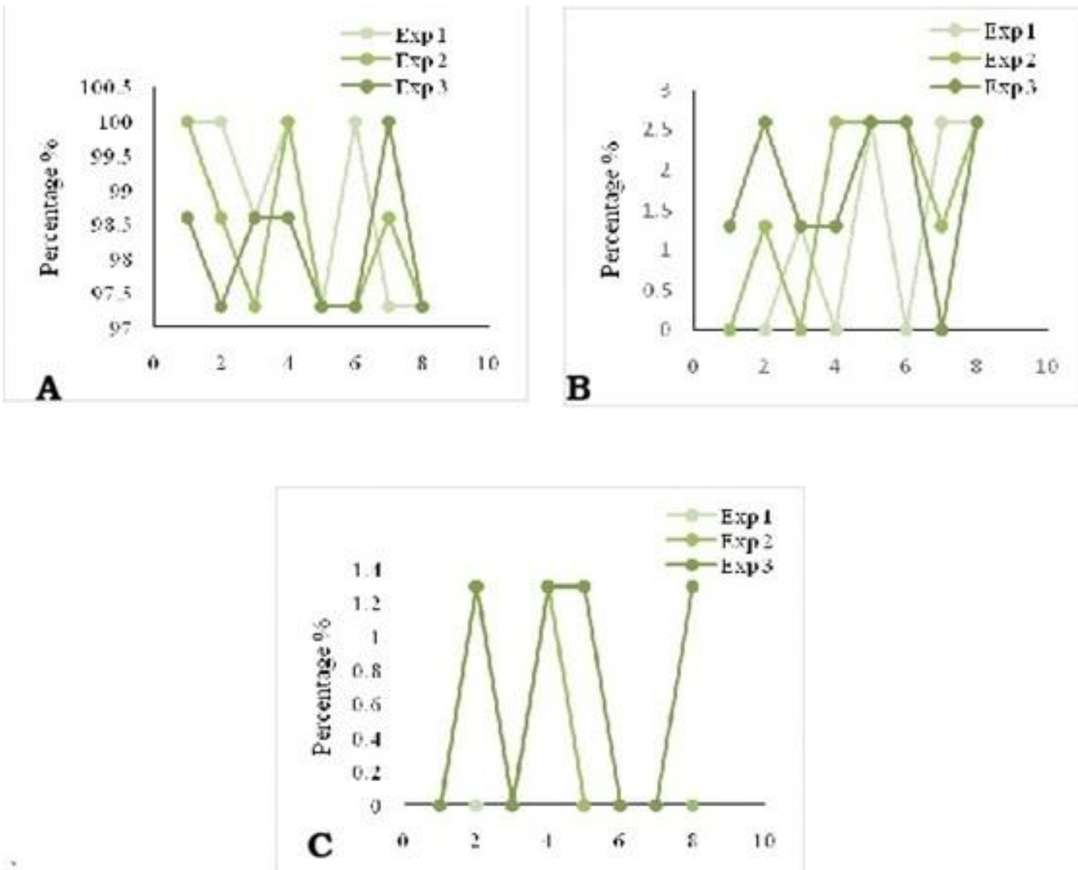

Fig. 3: Survival rate, mortality rate and cannibalism rate (%) of *Channa striata* fingerlings measured on a weekly basis: (a) Survival rate %, (b) Mortality rate %, (c) Cannibalism rate %.

Cannibalism is a common issue in murrel farming, especially at early stages when competition and stress levels are high. Inadequate nutrition often worsens this behaviour. Previous studies (Sharf *et al*., 2023) have shown that dietary L-tryptophan can reduce aggression in *Channa punctatus* by increasing serotonin levels in the brain. Similarly, our findings align with those of Samayanpaulraj *et al*. (2020), who reported that chitosan reduces cortisol and stress-related behaviours in murrel species. In the present study, chitosan appeared to play a similar role in calming aggressive tendencies.

Additionally, the chitosan diet showed a high satiation index, indicating improved feed utilization and appetite control. This likely contributed to the reduced incidence of cannibalism. The observed inverse relationship between satiation index and cannibalism supports the idea that nutritionally satisfying diets are key to reducing aggression in young carnivorous fish.

Conclusion

This study clearly demonstrates that dietary supplementation with chitosan, derived from *Artemia* shell waste, significantly improves early-stage growth, survival, and behavioural stability in *Channa striata* fingerlings. Among the three diets tested, the chitosan-based feed resulted a better results in final body weight, specific growth rate, feed conversion efficiency, and protein utilization, while notably reducing mortality and cannibalism. Chitosan not only enhanced nutrient absorption but also provided immune-protective and stress-reducing effects that helps to mitigate the cannibalism, a key issue in murrel fingerlings culture. In contrast, the black soldier fly larvae (BSFL) diet, though rich in protein, resulted in elevated mortality and aggressive behaviour, likely due to its high lipid content and detrimental effects on water quality. By integrating chitosan as a functional additive into fish feed, this research addresses a critical need for feed strategies that support both physiological development and behavioural regulation during the early stages of murrel fingerlings. Dietary chitosan in fish feed represents a promising bioactive compound for enhancing growth performance and disease resistance in future freshwater aquaculture systems.

Ethical Statement

This study was approved by ethical committee IAEC of Trichy Research Institute of Biotechnology, approval number TB/IAEC/2024/019.

Author Contributions

Each author has contributed equally to the study's planning, analysis, writing, and editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

The authors declare no conflicts of interest.

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