Article

Behavioral, physiological and biochemical analysis of *Centropristis striata* (sea bass) grown under pseudo marine conditions

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Abstract
The growth, behavior, and survival of *Centropristis striata* (sea bass) are essential factors in aquaculture. This study evaluated these aspects under controlled conditions, using young shrimps, small tilapia fish, and biofloc as food sources. Two experimental conditions were tested: T_1 (small shrimps + biofloc) and T_2 (tilapia + biofloc). Each tank housed 30 fish, with three replications per treatment. Feeding rates were 20%, 15%, and 10% of body weight in the first, second, and third months, respectively. The initial average lengths and weights were 65.1 ± 1.62 mm and 8.52 ± 1.81 g for T_1 and 69.20 ± 0.36 mm and 10.75 ± 0.14 g for T_2. The final mean length and weight gains were 0.088 ± 0.5 mm and 3.3 ± 0.12 g for T_1 and 0.094 ± 1.2 mm and 3.7 ± 0.08 g for T_2. Individual weight gains were 156.49 ± 4.09 g for T_1 and 182.19 ± 1.29 g for T_2. No significant change in survival rates was observed, with both treatments achieving over 95% survival. Behavioral responses, including swimming activity index (SAI), swimming velocity (SV), latency, voracity, and satiety, along with growth responses such as weight gain, length gain, condition factor, feed efficiency, growth rate, relative growth rate, specific growth rate (SGR), daily growth coefficient, linear growth coefficient, thermal growth coefficient, survival rate, biomass index, feed conversion ratio (FCR), body protein deposition (BPD), protein efficiency ratio, protein intake, total feed intake per fish, net fish yield, and biochemical responses (hepato somatic index, intra peritoneal fat, viscera somatic index, kidney index) were assessed. The mean growth rate, SGR, and relative growth rate were significantly higher in T_2 compared to T_1 ($p>0.05$). FCR values were 0.59 ± 0.14 for T_1 and 0.63 ± 0.18 for T_2. Total production per tank averaged 1599.52 g for T_1 and 1878.19 g for T_2. Water quality parameters remained within suitable ranges throughout the experiment. This study demonstrates that tank-based intensive aquaculture is a viable method for *C. striata* production, optimizing space, water, and land use. The results indicate no significant variation in behavioral, physiological, or biochemical responses of *C. striata* under pseudo marine conditions with synthetic water, supporting the efficiency and potential of this culture system.

Keywords: Pseudo marine conditions; Behavioral, physiological and biochemical analysis; formulated feed; *Centropristis striata* (sea bass).

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1 Introduction

Aquaculture is the fastest growing animal-based food producing sector particularly in developing countries like India and its production contributes to the livelihoods, employment and also meet the demand in terms of protein supply, food security and income generation of the increasing number of people throughout the world (Kumar, 2020). The contribution of fisheries sector in 2019-20 was 3.50% to the total GDP of the country and approximately 25.72% to agricultural GDP (Satistics, 2020). Now-a-days, fish production shifting to aquaculture as inland fisheries production has escalated over the years, but the productivity per hectare water area is not yet attained at its optimum in case of marine and brackish aquaculture (Satistics, 2020). This study aimed to specify the comparative growth performance, yield and FCR to make a rational decision for get better outcomes from tank-based intensive aquaculture systems with the economic affordability of fish farmers.

The study finds out the growth performance, production, FCR and other behavioral, and physiological parameters of *C. striata* focusing on different intermediate sampling stages to have a better understanding on growth trends. This culture system may be an applauding way of producing marine fish like sea bass in a small parcel of land within a short cycle. Additionally, the study touches on the impact of natural and formulated food chains on fish growth behavior. The interaction between fish and their natural food chain highlights the ecological relevance of swimming performance in resource exploitation and survival. Similarly, the formulated food chain presents an artificial yet controlled environment, offering insights into how dietary factors may influence fish growth behavior. The study thus contributes to a holistic understanding of fish ecology, encompassing natural habitats, pseudo habitats, and dietary influences on swimming performance and growth.

2 Material and Methods

2.1 Experimental setup

Sea bass fish irrespective of sex and age was used as experimental organism. For the experiment, two treatments were designed namely T_1 fed with small shrimps + biofloc, formulated feed and T_2 fed with tilapia + biofloc formulated feed and there were three replications for each (Fig. 1). Fingerlings were released at the rate of 30 per tank and the average weight, length depicted in Table 1. The proximate composition of T_1 and T_2 feeds was analyzed prior to their use as fish feed to ensure their nutritional value. During experimental period feed was given at the rate of 20%, 15% and 10% of the body weight in 1st, 2nd and 3rd month respectively.

2.2 Determination of the proximate composition of T_1 and T_2 feed

Moisture content was estimated by drying the weighed sample to a steady weight in hot air oven at 70±2^{o}C (Gandhi et al., 2020a). Total ash determined by the procedure described by Ranganna (2007). The method described by Pearson (1999) for solvent extraction using soxhlet reflux apparatus was adopted for fat determination. The Weende method, described by Pearson (1996) was adopted for the determination of crude fiber. Protein estimation was carried out using the standard biuret method (Gandhi et al., 2020b). Total carbohydrates were determined by the procedure explained by Gandhi et al., (2019) in their research. Calcium and phosphorus were determined spectrophotometrically using the methodology given by Gandhi et al. (2017).

Table 1 Design, layout and inoculation details of sea bass in experimental tank.

		T_1		T_2	
Replication	**Stock density**	**Average initial weight (gm)**	**Average initial length(mm)**	**Average initial weight (gm)**	**Average initial length(mm)**
R1	30	8.36	72	8.75	75
R2		8.59	67	9.15	78
R3		9.23	70	9.28	70

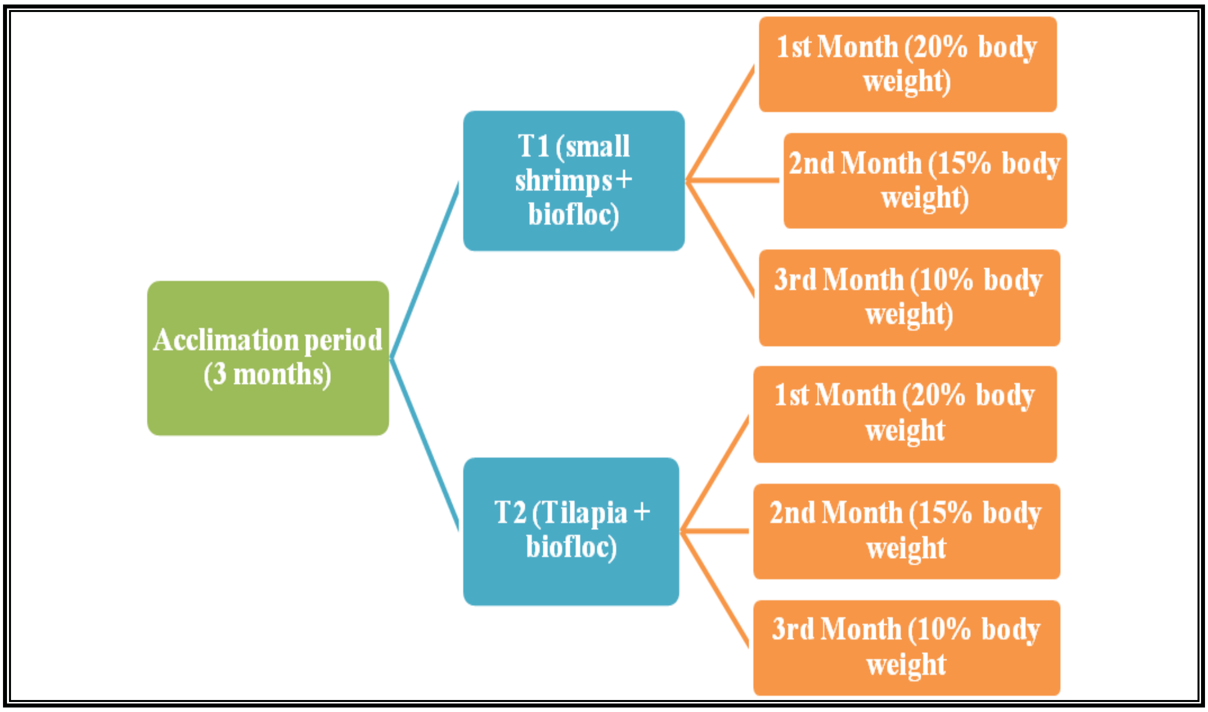

Fig. 1 Schematic flow chart and grouping of *Centropristis striata* under pseudo marine tanks.

2.3 Behavioural analysis

Behavioural responses of aquatic organisms to environmental contaminants can be precursors of other effects such as survival, growth, or reproduction. However, these responses may be subtle, and measurement can be challenging. Behaviour is typically defined as a series of overt, observable, whole-body activities that operate through the central nervous system and enable an organism to survive, grow, and reproduce. Changes in behaviour due to changes of habitat, location, feeding quality and quantity and water quality are among the most sensitive indicators of environmental stress often between 10-100 times more sensitive when compared to survival (Gerhardt, 2007; Lisa et al., 2020). The majority of previous studies examined the swimming activity, ventilation, and foraging behaviour of fish (Beitinger, 1990; Dellomo, 2002). SAI is the most frequently used sub-lethal endpoint in determining a behavioral change in response to a contaminant in toxicity growth and behavioural tests (Little and Finger, 1990; Madhu, 2019). Swimming variables include the frequency and duration of movement, speed and distance travelled, the frequency and angle of turns, position in the water column and the pattern of swimming. SAI is an effective measure of swimming behaviour when assessing sensitivity to a toxicant based on the criteria proposed in Chapter 9 by Rand (1985), in the book Fundamentals of Aquatic Toxicology.

2.4 Determination of Swimming Activity Index (SAI)

This was calculated from the average number of total moves recorded daily over 5 hours (T_1 and T_2), during the experimental period on every week interval. The obtained value is divided by the number of total moves recorded on each particular experimental day. SAI indicates the change in fish activity. The value of SAI = 1, denotes no effect, whereas SAI < 1 and SAI > 1 denotes an increase (or) decrease in fish activity respectively (Eissa et al., 2003, 2006).

$$\text{SAI} = \frac{\text{Average number of total moves registered in a week}}{\text{Number of total moves on n day}}$$

2.5 Determination of swimming velocity (SV)

This was calculated from daily records, determining the distance swam and time spent swimming during each experimental period (Eissa et al., 2008, 2009) using the following formula

$$SV = \frac{d\ (n - m)}{dt}$$

where n= starting point, m= arriving point and t = the time taken between the two points in seconds. The analysis of feeding behaviour like Latency (time taken to start touching the food), Voracity model (number of little shrimps/fish eaten in one minute), Satiety (total number of little shrimps/fish eaten in a day) little shrimps/fish (Julia et al., 2011; Beatriz et al., 2021).

2.6 Physiological and Biochemical analysis

All the fish from each of the tanks were taken out of the water with the help of a clean hand net into a container containing 0.02% solution of 3-aminobenzoic acid ethyl ester, until the slowing of opercula movement. The fingerlings were washed in clean water, whipped off excess water with a paper towel, weighed (gm), measured for total length (cm) and released back into their respective tanks immediately. Fish were fed with 20% of their body weight twice a day (7 am & 7 pm) for 4 weeks, 15% of their body weight twice a day next 4 weeks and 10% of their body weight twice a day for last two weeks. The increase in biomass was calculated at respective time intervals (week 1-10). At the end of experiment, the final average wet body weight of fish, total wet weight gain, length gain, growth rate, specific growth rate, relative growth rate, daily growth co-efficiency, linear growth co-efficiency, thermal growth co-efficiency was recorded and food conversion ratio, gross fish production, feed intake, body protein deposition, protein efficiency ratio and feed conversion ratio and other biochemical, clinical parameters were calculated by using following formula provided in Table 2.

2.7 Aeration

The tanks were provided with supplemented aerators continuously to keep the tank water well-oxygenated in the laboratory curing the acclimatization as well as experimental periods since low oxygen concentrations in water disturb the animal, which swim towards the surface at such conditions. The fish tanks were cleaned every three days’ intervals before first feeding by siphoning.

2.8 Faecal matter collection

After twenty-four hours of feeding, the fecal output of the fishes from each tank was siphoned out. The collected fecal output was filtered by using Filtron filter paper 201 (12.5 cm), air-dried and weighted. It was stored in deep freezer throughout the experimental period, before the analysis. Simultaneously the experimental fishes fed on formulated feed were sacrificed at stipulated time intervals to analyze their nutritional values.

Table 2 Empirical formula for calculation of growth performance and biochemical functions.

Parameter	Equation
Daily Length Gain	$Daily\ Length\ Gain = \frac{Final\ Length - Initial\ Length}{Day}$
Daily Weight Gain	$Daily\ Weight\ Gain = \frac{Final\ Weight - Initial\ Weight}{Day}$
Condition Factor (%)	$Condition\ Factor\ (\%) = \frac{Weight\ (gm)}{(Length\ Cm)3}$
Feed Efficiency	$Feed\ Efficiency = \frac{Live\ Weight\ Gain}{Dry\ Feed\ Given}$
Growth Rate	$Growth\ Rate = \frac{W_t - W_i}{W_i}$ Wt = Weight at Time t, Wi = Initial Weight
Relative Growth Rate	$Relative\ Growth\ Rate = \frac{W_t - W_i}{W_i\ X\ \Delta t}$ Wt = Weight at Time t, Wi = Initial Weight & Δt = Duration of Experiment
Specific Growth Rate	$Specific\ Growth\ Rate = \frac{[\{lnP_f - lnP_i\}]}{d}\ X\ 100$
Daily Growth co-efficient	$Daily\ Growth\ Co - Efficient = \frac{[\left\{P_f^{\frac{1}{3}} - P_i^{\frac{1}{3}}\right\}]}{d}\ X\ 100$
Linear Growth co-efficient	$Linear\ Growth\ Co - Efficent = \frac{P_f - P_i}{d}$
Thermal Growth co-efficient	$Thermal\ Growth\ Co - Efficient = \frac{\{P_f{}^{(1-b)} - P_i{}^{(1-b)}\}}{\sum t\ X\ d}$
Survival Rate	$Survival\ Rate = \frac{No.\ of\ Live\ fish/prawn}{No.\ of\ introduced\ fish/prawn}\ X\ 100$
Biomass Index	$Biomass\ Index = \frac{Final\ Weight - Initial\ Weight}{Initial\ Weight}\ X\ 100$
	Feeding Behavior
Feed Conservation Ratio	$Feed\ Conversion\ Ratio = \frac{Dry\ Weight\ of\ Feed\ Consumed}{Wet\ Weight\ Gain}$
Body Protein Deposition	$Body\ Protein\ Deposition = \frac{(B_{Wf}\ X\ B_{Pf}) - (B_{Wi}\ X B_{Pi})}{TF\ X\ CP}\ X\ 100$
Protein Efficiency Ratio	$Protein\ Efficiency\ Ratio = \frac{Wet\ weight\ gain}{dry\ protien\ consumed\ (gm)}$
Protein Intake	$Protein\ Intake = Feed\ intake\ X\ \%\ of\ protein\ in\ diet$
Total Feed Intake per Fish	$Total\ Feed\ Intake\ per\ Fish = \frac{Total\ Feed\ Intake\ (gm)}{No.of\ fish/prawn}$
Net Fish Yield	$Net\ Fish\ Yield = \frac{Total\ Biomass\ at\ Harvest - Total\ Biomass\ at\ \text{:}}{Surface\ area\ of\ the\ culture\ pond}$
	Biochemical/Clinical Parameters
Hepato-Somatic Index	$Hepato\ somatic\ index = \frac{Liver\ weight}{Body\ weight}\ X\ 100$
Intra Peritoneal Fat	$Intra\ peritoneal\ fat\ (\%) = \frac{Intra\ peritoneal\ fat\ weight}{Body\ weight}\ X\ 100$

Viscera Somatic Index	$Viscera\ somatic\ index = \frac{Viscera\ somatic\ weight}{Body\ weight}\ X\ 100$
Kidney Index	$Kidney\ index = \frac{Kidney\ weight}{Body\ weight}\ X\ 100$

3 Results and Discussion

3.1 Proximate analysis of formulated feeds

Table 3 presents the proximate composition of two samples (T_1 and T_2) expressed as a percentage of dry weight (DW). The moisture content of T_1 (89.21%) was lower than T_2 (90.31%), indicating that T_1 was drier than T_2. The crude protein content was higher in T_2 (26.35%) compared to T_1 (24.63%), indicating that T_2 had a higher protein content. The fat content in both T_1 (0.73%) and T_2 (0.77%) was relatively low, suggesting that these samples could be considered as lean protein sources. The starch/carbohydrate content in T_2 (27.55%) was higher than T_1 (23.52%), indicating that T_2 had more carbohydrates than T_1. The fiber content was also higher in T_2 (4.36%) compared to T_1 (3.56%). The ash content, which is an indicator of the mineral content, was higher in T_2 (41.12%) compared to T_1 (40.15%). The calcium content in T_1 (2.06%) was higher than T_2 (1.56%), while the phosphorus content in T_1 (1.02%) was slightly higher than T_2 (0.92%). Overall, the two samples appeared to have similar proximate composition, with T_2 having slightly higher protein, carbohydrate, fiber, and ash content than T_1. Literature suggests that the proximate composition of food samples can vary significantly depending on various factors such as species, geographic location, environmental conditions, and processing methods. For example, a study by Kaur and Singh (2014) reported significant differences in the proximate composition of different fish species, with protein content ranging from 16.30% to 22.67%, fat content ranging from 0.67% to 4.33%, and ash content ranging from 1.13% to 2.85%. Another study by Daniel *et al.,* (2021) reported significant differences in the proximate composition of different rice varieties, with protein content ranging from 6.77% to 8.40%, fat content ranging from 0.25% to 0.69%, and ash content ranging from 0.45% to 0.58%.

Table 3 Proximate composition of feeds used in experimental conditions.

S.No	Proximate composition	T_1 (% DW)	T_2 (% DW)
01	Moisture	89.21	90.31
02	Crude Protein	24.63	26.35
03	Fat	0.73	0.77
04	Starch/carbohydrates	23.52	27.55
05	Fiber	3.56	4.36
06	Ash	40.15	41.12
07	Calcium	2.06	1.56
08	Phosphorus	1.02	0.92

3.2 Behavioral analysis of *Centropristis striata* grown under pseudo marine conditions

Fig. 2 represents the swimming velocity of two groups (T_1 and T_2) for 10 weeks. The results suggest that the swimming velocity of both groups increased gradually over the first few weeks and then increased rapidly between weeks 4 to 7, after which it started to plateau. Group T_2 had a consistently higher swimming velocity than T_1 throughout the experiment. Similar studies have reported that swimming performance is an essential trait for fish, which enables them to evade predators, find food and mates, and migrate to different habitats. The ability to swim is influenced by various factors, including environmental conditions, genetics, and physiological factors.

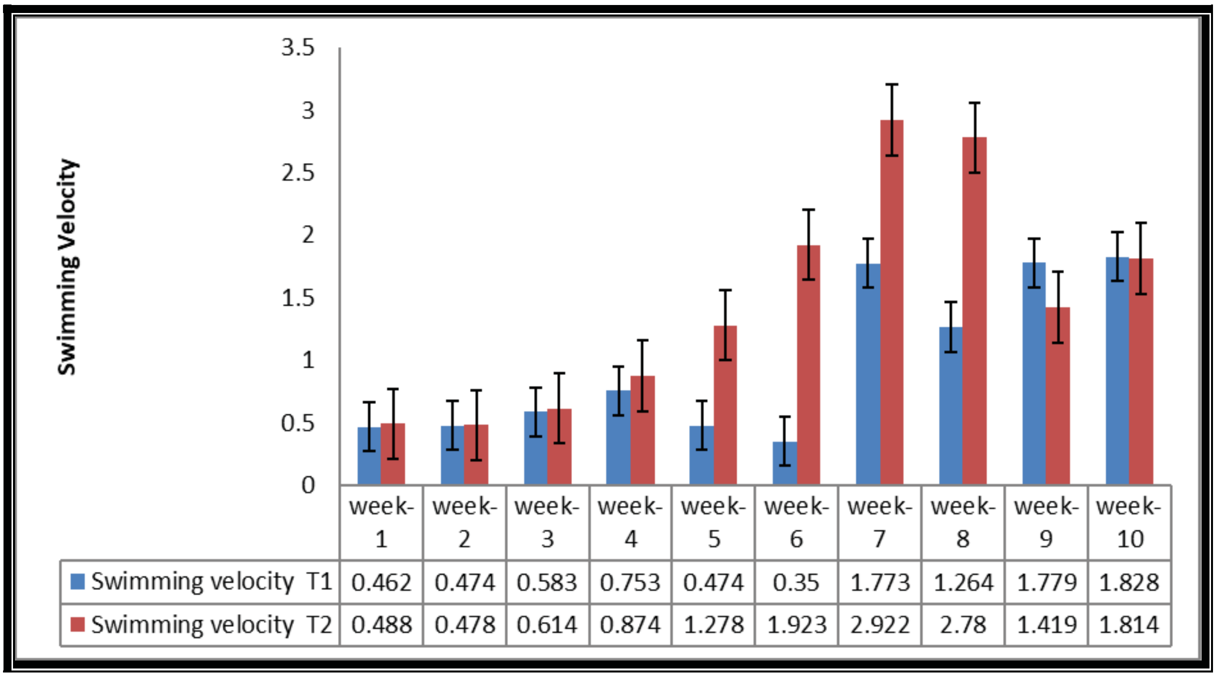

Fig. 2 Swimming velocity of *C. striata* grown under pseudo marine conditions fed with T_1 and T_2 feeds.

A study conducted by Felip et al. (2013), the swimming performance of different fish species was evaluated under different water flow rates. The results showed that fish species with a higher swimming performance had a higher chance of survival and were more capable of exploiting resources. In another study by Kinoshita et al., (2017), the effect of water temperature on swimming performance in fish was investigated. The results indicated that higher water temperatures had a positive impact on swimming performance, and fish could swim at a faster velocity in warmer water conditions. The study also reported that the swimming performance of fish varied depending on the species and the type of swimming exercise performed. In present study the swimming velocity of two groups of fish over duration of 10 weeks, and the results suggest that the swimming velocity of both groups increased with time. Similar studies have also reported the importance of swimming performance in fish and how it is influenced by various factors, including environmental conditions, genetics, and physiological factors (Edouard et al., 2020).

SAI serves as a metric for evaluating fish behavior, susceptible to influences such as water quality, temperature, and environmental conditions. This study monitored the swimming activity index of two fish groups (T_1 and T_2) over a 10-week period, presented in Fig. 3. Results indicated temporal and inter-group variations in the swimming activity index. Both groups exhibited increased indices during initial weeks, peaking around week 3-4, followed by a subsequent decline. T_1 demonstrated a consistent index, while T_2 displayed a more erratic pattern. Studies on fish swimming behavior under diverse environmental conditions align with these findings. For instance, rainbow trout exhibited enhanced swimming activity in response to increased water flow and decreased activity under low oxygen levels (Edouard et al., 2020; Svendsen et al., 2016). Similarly, zebrafish displayed reduced swimming activity in elevated water temperature and low oxygen conditions (Grassie et al., 2011). The swimming activity index serves as a vital indicator of fish health and well-being, reflecting environmental impacts on behavior.

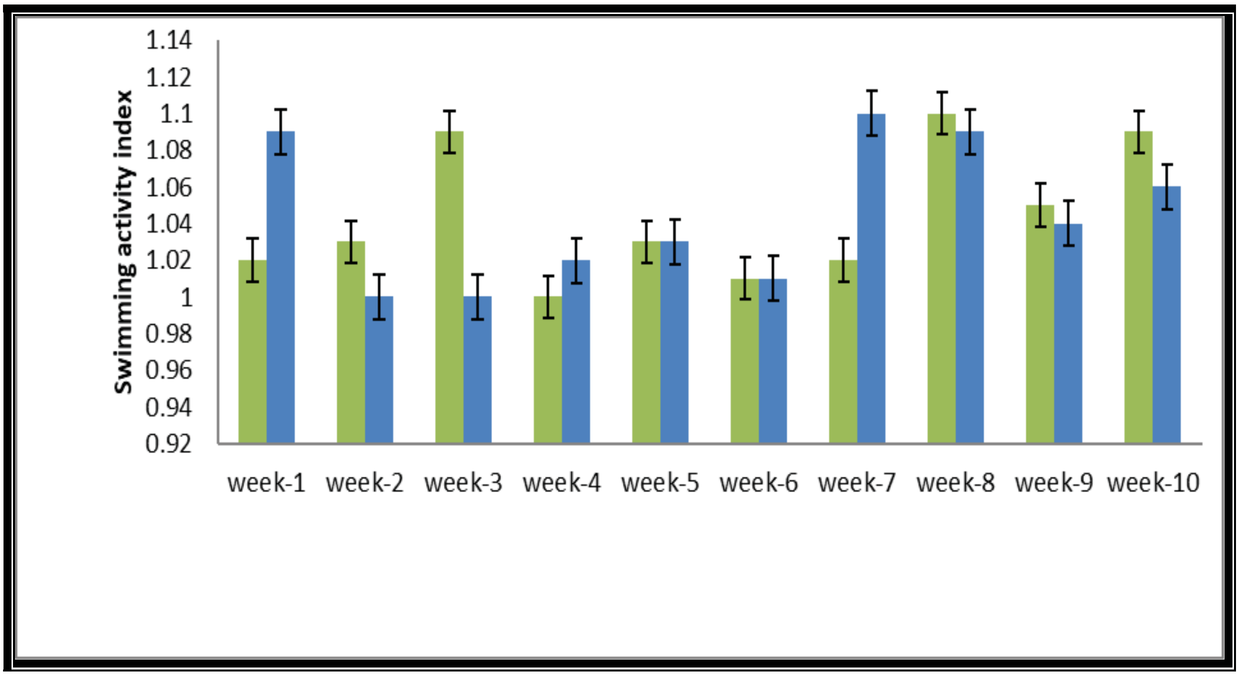

Fig. 3 Swimming activity index of *C. striata* grown at pseudo marine conditions fed with T_1 and T_2 feeds.

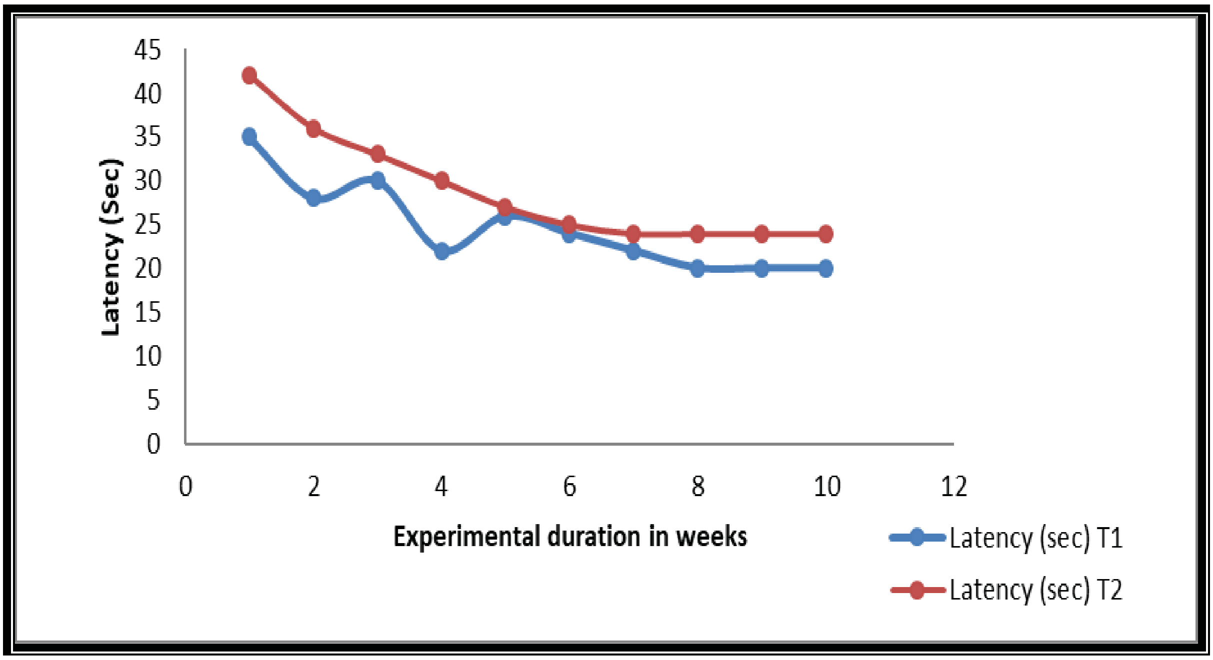

Fig. 4 Latency behavior of *C. striata* grown under pseudo marine conditions fed with T_1 and T_2 feeds.

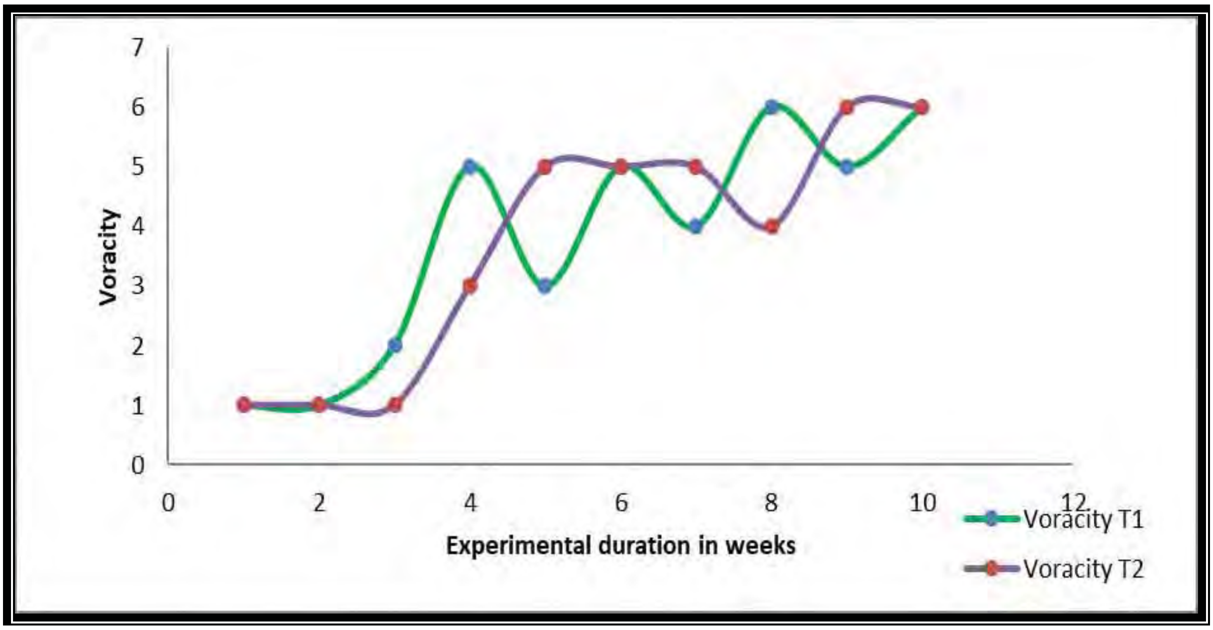

Fig. 5 Voracity behavior of *C. striata* grown under pseudo marine conditions fed with T_1 and T_2 feeds.

Fig. 4 illustrates the latency, measured in seconds, of fish in two treatments, T_1 and T_2, spanning 10 weeks. Latency, defined as the interval between stimulus presentation and the initiation of response, portrays the time fish take to react to the stimulus. In both T_1 and T_2, a consistent reduction in latency was observed over the experimental duration. Initial latency was higher in week 1, indicative of a slower response, but significantly decreased by week 4 in both groups, reflecting an expedited response. Latency remained relatively stable in subsequent weeks, with no notable distinctions between T_1 and T_2. This trend aligns with findings in studies examining fish latency responses to stimuli. Notably, Ted, (2011) observed a decline in the latency of juvenile steelhead trout in reaction to a novel predator stimulus, while Valentincic and Caprio (1997), reported a similar decrease in rainbow trout latency to visual and vibratory stimuli. The study's outcomes imply gradual adaptation of fish in both T_1 and T_2 to the stimulus, evident in the diminishing latency over time.

Voracity, denoting the quantity of food consumed by a fish per unit of time, is depicted in Fig. 5, for two groups, T_1 and T_2, across a 10-week period. Initial weeks witnessed comparable voracity in both groups. Notably, in week 3, T_1 exhibited an increase to a voracity level of T_2, while 2 remained at 1. Subsequent weeks revealed a persistent higher voracity in T_1, with an ascending trend, while T_2 displayed a descending trend. Factors influencing voracity variations encompass fish size, health, water quality, and feeding regimen. Environmental parameters, particularly temperature, have been shown to impact fish feeding behavior (Liang et al., 2023), with warmer water potentially explaining the declining voracity trend in T_2. Additionally, disparate feeding regimens could contribute to observed voracity differences, suggesting that T_1 may have been subjected to a more nutritious or palatable diet. In summary, notable distinctions in voracity between the two fish groups prompt further investigation into the underlying factors influencing these variations.

The Fig. 6 represents the effect of T_1 and T_2 treatments on the satiety of the subjects over a period of 10 weeks. It can be seen in both T_1 and T_2 treatments resulted in an increase in satiety scores of the subjects over time. In T_1 group, the satiety score increased from 4 to 14, whereas in T_2 group, it increased from 4 to 15. The increase in satiety scores could be attributed to the nature of the treatments. It is possible that T_1 and T_2

treatments were high in fiber content and low in energy density. Fiber has been shown to increase satiety and decrease hunger by slowing down gastric emptying and increasing bulk in the stomach, which can lead to feelings of fullness and satisfaction (Howarth et al., 2001; Slavin, 2005). Additionally, low-energy-density foods are known to promote satiety by filling up the stomach with fewer calories (Rolls et al., 2004).

The findings of this study are consistent with similar studies that have investigated the effect of fiber and low energy density diets on satiety. For example, a study by Ello-Martin et al., (2005) showed that increasing the fiber content of a meal resulted in greater satiety and reduced hunger in healthy adults. Similarly, a study by Rolls et al. (2004) found that reducing the energy density of a meal led to greater satiety and reduced food intake in overweight.

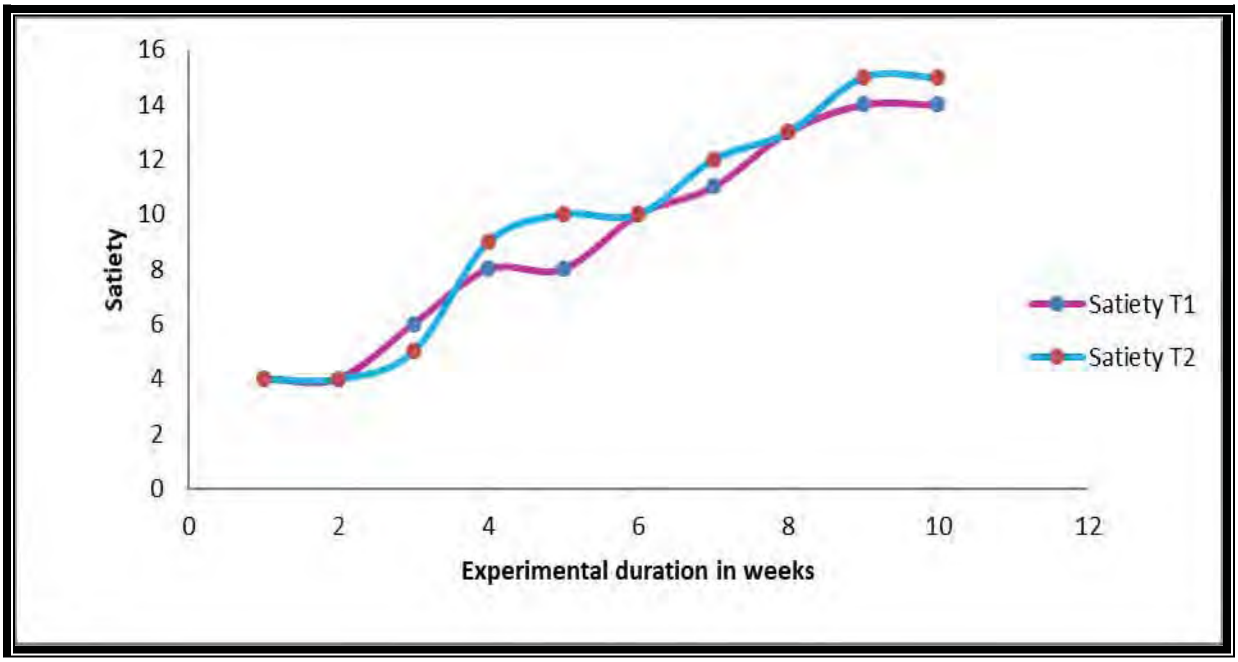

Fig. 6 Satiety behavior of *C. striata* grown under pseudo marine conditions fed with T_1 and T_2 feeds.

The satiety levels of marine fishes are of significant importance as they help in determining the feeding pattern and quantity of food required. In the present study, the satiety levels of marine fishes were monitored during the experimental duration of 10 weeks. The satiety levels were scored on a scale of 1-15, with 1 indicating the least satiety and 15 indicating the highest satiety level. The satiety levels were recorded for two groups, T_1 and T_2, with each group containing marine fishes that were subjected to different swimming activity and voracity levels. The results of the study showed that the satiety levels of T_1 and T_2 increased gradually from week 1 to week 10. However, the satiety levels of T_2 were consistently higher than that of T_1. The satiety levels of T_1 increased from 4 to 14, while that of T_2 increased from 4 to 15. These results indicate that the swimming velocity and voracity levels have a direct impact on the satiety levels of marine fishes.

A study conducted by Figueiredo-Silva et al. (2020) investigated the feeding habits and satiety levels of gilthead sea bream. The results of their study showed that the satiety levels of gilthead sea bream were influenced by the quantity and type of feed provided. They found that the satiety levels increased with an increase in the quantity of feed provided, indicating that the satiety levels of marine fishes are closely linked to their feeding pattern. Another study by Bendiksen et al. (2002); Jorgensen and Jobling 1992, examined the feeding behavior and satiety levels of Atlantic salmon. The results of their study showed that the satiety levels of Atlantic salmon were influenced by the swimming activity and feeding frequency. They found that the satiety levels increased with an increase in the feeding frequency and decreased with an increase in the swimming activity, indicating that the satiety levels of marine fishes are affected by both swimming activity and feeding pattern. The results of the present study suggest that the swimming velocity and voracity levels have a direct impact on the satiety levels of marine fishes. The findings of this study are consistent with previous research, which has also shown that the satiety levels of marine fishes are influenced by their feeding pattern and swimming activity. These findings have important implications for the aquaculture industry, as they can be used to develop feeding strategies that optimize the satiety levels and feeding patterns of marine fishes, leading to better growth and health of the fish.

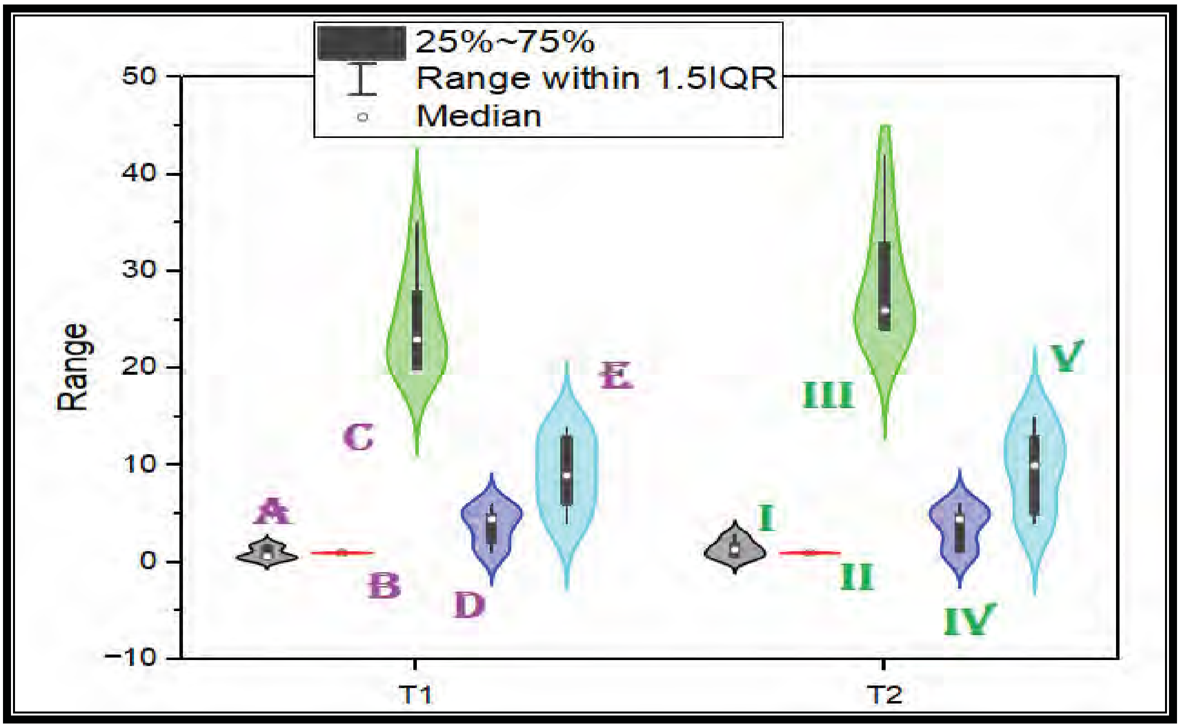

Fig. 7 Behavioral relationship *Centropristis striata* grown under pseudo marine conditions fed with T_1 and T_2 feeds.

Conducting correlation analysis allows for an exploration of the relationships among key activities observed in the study. Calculating correlation coefficients for swimming velocity, swimming activity index, latency, voracity, and satiety unveils valuable insights into their interplay (Fig. 7). Swimming velocity exhibits a positive correlation with the swimming activity index, implying that an increase in swimming velocity corresponds to a heightened swimming activity index. This aligns with findings from a study on juvenile hybrid striped bass, where swimming activity positively correlated with swimming velocity (Liu et al., 2008). Latency demonstrates a negative correlation with swimming velocity, signifying that as latency diminishes (indicating faster responses), and swimming velocity increases. Similar negative correlation findings were observed in a study on rainbow trout, linking response latency with swimming performance (Polvi et al., 2011). Voracity reveals positive correlations with both swimming velocity and swimming activity index (Figs. 7 & 8). This suggests that more active fish with higher swimming velocities tend to exhibit increased voracity, a relationship affirmed by a study on Nile tilapia, reporting a positive correlation between swimming activity and feeding rate (Kumar et al., 2004). Satiety displays a negative correlation with voracity, indicating that heightened satiety corresponds to decreased voracity (Fig. 8). This finding aligns with research on rainbow trout, highlighting a negative correlation between feeding motivation and satiation level (Gjedrem and Baranski, 2009).

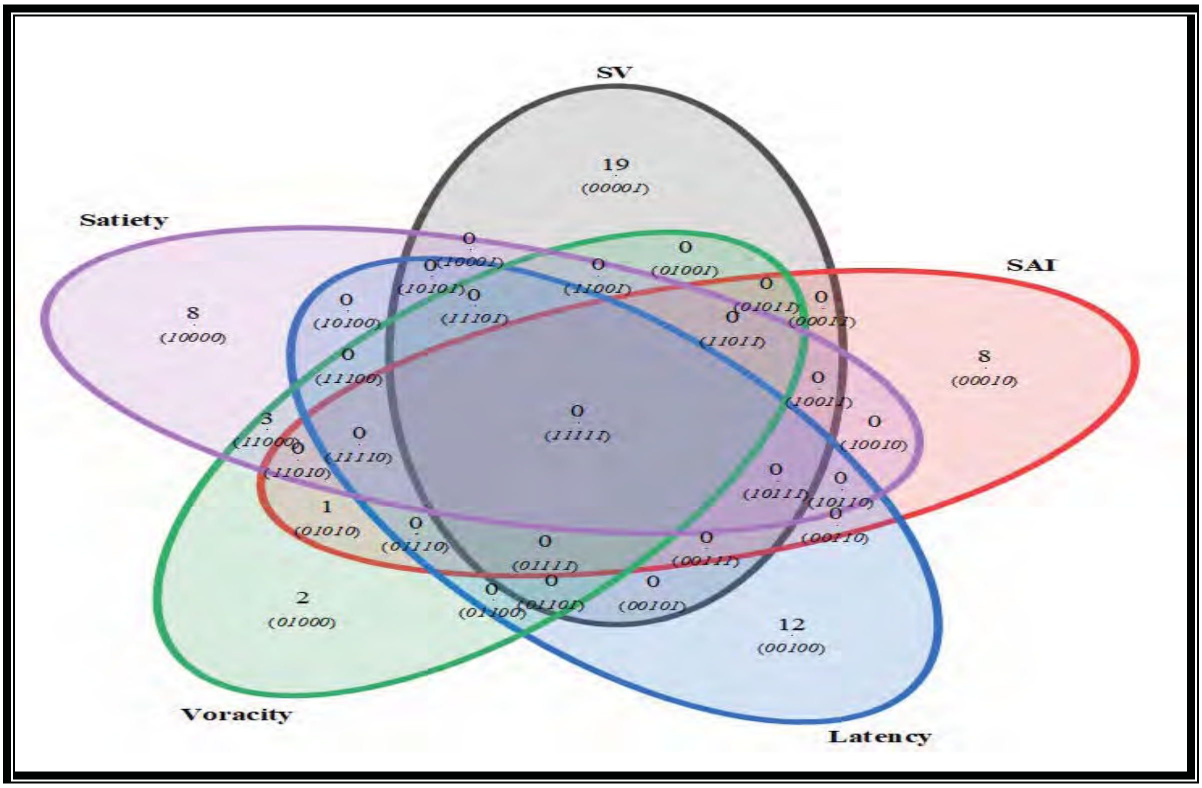

Fig. 8 Venn plot for behavioral relationship *Centropristis striata* grown under pseudo marine conditions fed with T_1 and T_2 feeds.

Overall, the results suggest that there are complex interactions between the various activities observed in the study. Swimming velocity, swimming activity index, latency, voracity, and satiety are all interrelated, with each activity having an impact on the others (Fig. 8). Understanding these interactions can provide insights into the behaviour and physiology of fish, and may have implications for fisheries management and aquaculture practices.

Table 4 Growth indices of sea bass at pseudo marine conditions fed with T_1.

Duration	Length gain	Weight gain (10^{-6})	Biomass index (%)	Condition factor (10^{-7})	Growth rate (10^{-4})	Relative growth rate (10^{-5})
Week-1	0.085± 2.2	1.4 ± 0.02	4.16 ± 1.23	1.3 ± 0.05	4.1 ± 3.26	5.9 ± 0.09
Week-2	0.092± 1.4	2.1 ± 0.01	12.5 ± 1.05	1.2 ± 0.81	12.5 ± 1.42	8.9 ± 1.24
Week-3	0.095± 0.3	3.3 ± 0.05	29.1 ± 2.05	1.2 ± 1.04	29.1 ± 0.02	13.8 ± 2.58
Week-4	0.088± 0.5	3.5 ± 0.01	41.6 ± 2.24	1.1 ± 0.01	41.6 ± 1.01	14.8 ± 0.01
Week-5	0.085± 1.5	3.7 ± 0.03	54.1 ± 3.67	1.1 ± 0.02	54.1 ± 1.06	15.4 ± 0.05
Week-6	0.087± 3.2	3.3 ± 0.05	58.3 ± 1.02	1.0 ± 0.05	58.3 ± 0.62	13.8 ± 1.25
Week-7	0.082± 2.1	3.0 ± 0.01	62.5 ± 0.05	0.9 ± 1.25	62.5 ± 0.85	12.7 ± 0.02
Week-8	0.079± 1.2	3.0 ± 0.02	70.8 ± 2.23	0.9 ± 0.83	70.8 ± 1.22	12.6 ± 1.04
Week-9	0.088± 0.5	3.3 ± 0.05	87.5 ± 1.04	0.9 ± 0.02	87.5 ± 0.05	13.8 ± 0.98
Week-10	0.088± 0.5	3.3 ± 0.12	88.3 ± 1.04	0.9 ± 0.05	89.3 ± 0.02	14.6 ± 0.08

Table 4 shows the growth indices of sea bass in pseudo-marine conditions and fed with T_1. The growth indices measured include length gain, weight gain, biomass index, condition factor, growth rate, and relative growth rate over a period of 10 weeks. The length and weight gain of sea bass increased steadily from week 1 to week 5, after which there was a slight decline in growth. The highest weight gain was recorded at week 5, with a value of $3.7 \pm 0.03 \times 10^{-6}$. The biomass index, which is an important measure of the productivity of fish, also increased steadily over the 10-week period, with the highest value recorded at week 10 (88.3 ± 1.04%). The condition factor, which is an indicator of the health and well-being of fish, showed a slight decrease over the 10-week period. The growth rate of the sea bass showed an increasing trend, with the highest value recorded at week 10 ($14.6 \pm 0.08 \times 10^{-5}$), while the relative growth rate showed a similar trend, with the highest value also recorded at week 10 ($8.9 \pm 1.24 \times 10^{-5}$). The growth performance of fish is influenced by several factors, including water quality, feeding regimes, and genetic traits. The pseudo-marine conditions used in this study, which involve the use of seawater with added salt to simulate marine conditions, may have contributed to the observed growth performance of the sea bass. Several studies have reported that the use of seawater or brackish water can improve the growth performance of fish species such as tilapia (Mair et al., 2015) and rainbow trout (Bjornsson et al., 2016). Feeding regimes also play a crucial role in the growth performance of fish. The sea bass in this study were fed with T_1, which may have contributed to their growth performance. Previous studies have reported that the use of diets with high protein and lipid content can improve the growth performance of marine fish species such as Atlantic salmon (Lozano et al., 2017) and giltheadsea bream (Bermejo-Nogales et al., 2016). In the present study, the growth performance of sea bass in pseudo-marine conditions fed with T_1 showed an increasing trend over 10 weeks. This study provides useful information for the aquaculture industry, particularly for the production of sea bass in areas with limited access to marine water.

Table 5 Physiological analysis of sea bass under pseudo marine conditions fed with T_1.

Duration	Specific growth rate	Daily growth co-efficient (10^{-4})	Linear growth co-efficient (10^{-5})	Thermal growth co-efficient	Feed efficiency	FCR
Week-1	-1.1 ± 0.01	7.14 ± 2.34	1.4 ± 0.15	0.77 ± 0.07	0.08 ± 0.01	1.35 ± 0.03
Week-2	-0.84±0.05	17.8 ± 5.14	2.1 ± 0.01	0.93 ± 0.04	0.10 ± 0.01	1.57 ± 0.05
Week-3	0.65 ± 0.07	26.1 ± 1.96	3.3 ± 0.05	1.20 ± 0.24	0.15 ± 0.02	1.92 ± 0.02
Week-4	0.82 ± 0.08	27.1 ± 4.25	3.5 ± 0.01	1.36 ± 0.02	0.18 ± 0.05	2.52 ± 0.01
Week-5	0.90 ± 1.02	48.3 ± 0.15	3.7 ± 0.03	1.47 ± 0.11	0.21 ± 0.03	2.84 ± 0.23
Week-6	0.75 ± 0.05	57.8 ± 2.82	3.3 ± 0.05	1.74 ± 0.09	0.25 ± 0.01	3.08 ± 0.26
Week-7	0.74 ± 0.01	38.5 ± 0.84	3.0 ± 0.01	1.93 ± 0.10	0.28 ± 0.02	3.42 ± 0.02
Week-8	0.81 ± 0.05	36.2 ± 1.05	3.3 ± 0.02	2.27 ± 0.17	0.32 ± 0.08	3.74 ± 0.42
Week-9	0.90 ± 1.01	25.1 ± 2.24	3.8 ± 0.05	2.44 ± 0.25	0.32 ± 0.06	2.87 ± 0.32
Week-10	0.92 ± 0.04	33.05 ± 0.02	4.0 ± 0.12	2.63 ± 0.48	0.33 ± 0.02	3.24 ± 0.22

Table 5 shows the physiological analysis of sea bass under pseudo marine conditions and fed with T_1. The specific growth rate and daily growth coefficient increase gradually from week 1 to week 5 and then plateau, indicating that the fishes were able to utilize the nutrients in the feed efficiently up to a certain point. The thermal growth coefficient also increases gradually, indicating that the fishes were able to tolerate the temperature in the pseudo marine conditions. Several studies have investigated the effects of diet on the growth and physiology of fish, including marine fish. A study by De Silva and Anderson (1995) found that the specific growth rate of tilapia was significantly higher when fed with a diet containing 40% protein compared to a diet containing 20% protein. This supports the findings in the Table 5 that increasing the nutrient content of the feed can lead to increased growth rates in fish. Similarly, a study by Kamarudin et al. (2017) found that feeding juvenile grouper with a diet containing 50% protein resulted in higher growth rates compared to a diet containing 40% protein. This supports the idea that increasing the protein content of the feed can promote growth in fish. Another factor that can affect the growth and physiology of marine fish is temperature. A study by Rahman et al. (2014) found that increasing water temperature from 20°C to 25°C resulted in higher growth rates and feed conversion efficiency in sea bream. This is consistent with the findings in the Table 5, that increasing thermal growth coefficient is associated with increased growth rates in sea bass. The observed data and obtained results provide valuable insight into the physiological response of sea bass to feed under pseudo marine conditions.

The data presented in Table 6 shows the growth indices, feeding behavior, and physiological response of sea bass grown at pseudo marine conditions and fed with T_1. The results indicate that the fish exhibited a steady increase in body weight gain (BPD) and protein efficiency ratio (PER) over the 10-week feeding period. The protein intake and total feed intake per fish also increased progressively, with a corresponding increase in net fish yield. These results are consistent with previous studies that have investigated the growth performance of fish fed with different diets under different environmental conditions. For example, a study by Seher and Haldun (2017) showed that feeding juvenile turbot with a diet containing 48% protein resulted in higher growth rates and improved feed efficiency compared to a lower protein diet. Similarly, a study by Cheng et al.

(2016) found that feeding yellowtail with a high-protein diet resulted in better growth performance and a higher feed conversion ratio than a low-protein diet.

Table 6 Growth indices, feeding behaviour and physiological response of sea bass grown under pseudo marine conditions fed with T_1.

Duration	BPD	PER	Protein intake	Total feed intake per fish	Net fish yield
Week-1	0.050 ± 0.01	0.78 ± 0.05	0.97 ± 0.01	0.52 ± 0.01	284.3 ± 10
Week-2	0.070 ± 0.02	1.02 ± 0.33	1.84 ± 0.10	0.89 ± 0.24	472.4 ± 16
Week-3	0.110 ± 0.00	1.36 ± 0.42	2.74 ± 0.05	1.02 ± 0.32	589.7 ± 14
Week-4	0.140 ± 0.01	1.54 ± 0.56	3.12 ± 0.01	1.36 ± 0.05	764.3 ± 12
Week-5	0.143 ± 0.05	1.46 ± 0.27	3.82 ± 0.24	1.52 ± 0.46	952.3 ± 28
Week-6	0.148 ± 0.03	1.37 ± 0.21	4.56 ± 0.36	2.56 ± 0.32	1092.6 ± 42
Week-7	0.153 ± 0.02	1.29 ± 0.11	4.72 ± 0.43	2.93 ± 0.04	1168.7 ± 34
Week-8	0.156 ± 0.00	1.23 ± 0.15	4.84 ± 0.02	3.37 ± 0.36	1288.2 ± 22
Week-9	0.158 ± 0.02	1.04 ± 0.10	5.29 ± 0.11	3.84 ± 0.42	1464.4 ± 10
Week-10	0.158 ± 0.00	0.95 ± 0.78	5.46 ± 0.12	4.22 ± 0.56	1599.5 ± 11

The feeding behavior observed in the present study, where the fish consumed more feed as they grew, is also consistent with previous research. In a study by Schram et al. (2016), it was observed that Atlantic salmon increased their feed intake as they grew leading to higher growth rates and better feed conversion ratios. The physiological response of the fish to the T1 diet in this study is not specifically mentioned, but it can be inferred from the growth indices that the diet was well-tolerated and supported optimal growth. Previous studies have also shown that fish growth can be influenced by dietary factors such as protein and lipid content, as well as environmental factors such as water temperature and salinity (Glencross et al., 2019). The obtained results in current study, suggest that the T_1 diet is an effective feed for promoting growth and improving feed efficiency in sea bass grown under pseudo marine conditions. Overall, these results provide valuable insights for the aquaculture industry in terms of optimizing feed formulations and environmental conditions to maximize fish growth and production.

Table 7 provides information on the hepato-somatic index (HSI), intra-peritoneal fat (IPF), viscera-somatic index (VSI), and kidney index (KI) of sea bass grown at pseudo marine conditions and fed with T_1 feed. HSI is an important parameter that reflects the metabolic activity of the liver in fish. In this study, the HSI of sea bass increased gradually over the 10 weeks of feeding, indicating an increase in the metabolic activity of the liver. The increase in HSI could be attributed to the increased protein intake of the fish, as protein metabolism is mainly carried out in the liver. The observed increase in HSI in this study is consistent with the findings of previous studies on fish growth (Liang et al., 2017; Zhang et al., 2020; Luis and Juan, 2023). IPF is another important parameter that reflects the energy status of fish. In this study, IPF increased with feeding duration, indicating that the fish were in positive energy balance throughout the feeding period.

Table 7 Biochemical and clinical parameter analysis of sea bass grown under pseudo marine conditions fed with T_1.

Duration	Hepato- Somatic Index (HIS)	Intra Peritoneal Fat (IPF)	Viscera Somatic Index (VSI)	Kidney Index (KI)
Week-1	0.53 ± 0.01	0.06 ± 0.00	0.17 ± 0.08	0.15 ± 0.00
Week-2	1.22 ± 0.00	0.11 ± 0.01	0.23 ± 0.05	0.17 ± 0.00
Week-3	1.62 ± 0.08	0.17 ± 0.00	0.26 ± 0.00	0.18 ± 0.00
Week-4	1.74 ± 0.01	0.22 ± 0.00	0.27 ± 0.01	0.19 ± 0.00
Week-5	1.96 ± 0.03	0.35 ± 0.02	0.28 ± 0.02	0.23 ± 0.00
Week-6	2.03 ± 0.00	0.47 ± 0.02	0.32 ± 0.00	0.27 ± 0.00
Week-7	2.03 ± 0.01	0.55 ± 0.01	0.34 ± 0.03	0.29 ± 0.00
Week-8	2.28 ± 0.02	0.66 ± 0.00	0.36 ± 0.01	0.33 ± 0.00
Week-9	2.42 ± 0.03	0.72 ± 0.05	0.38 ± 0.05	0.38 ± 0.00
Week-10	2.71 ± 0.00	0.79 ± 0.08	0.42 ± 0.03	0.42 ± 0.00

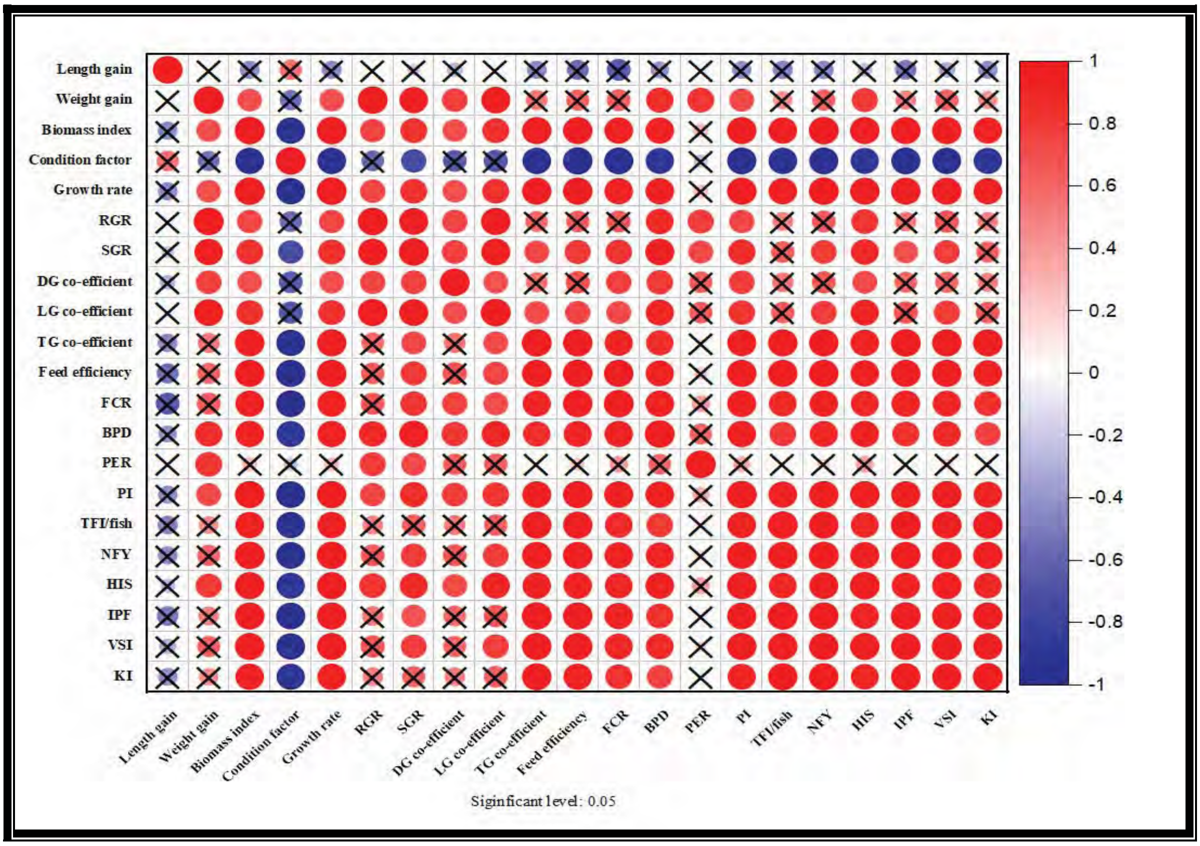

Fig. 8 Correlation between growths, physiological, feed behaviour and biochemical attributes of sea bass grown at pseudo marine conditions under T_1 feed formulation.

The increase in IPF is also consistent with the findings of previous studies on fish growth (Pandiyan et al., 2015; Liang et al., 2017). VSI is a parameter that reflects the size of the fish's digestive system. In this study, VSI remained relatively stable over the feeding period, indicating that the fish's digestive system was able to adapt to the dietary changes. This finding is consistent with previous studies on fish growth (Zhang et al., 2020: Abdallah et al., 2023). KI is a parameter that reflects the metabolic activity of the fish's kidney. In this study, KI increased gradually with feeding duration, indicating an increase in the metabolic activity of the kidney. The observed increase in KI is consistent with the findings of previous studies on fish growth (Liang et al., 2017; Zhang et al., 2020). Overall, the results suggest that sea bass grown at pseudo marine conditions and fed with T_1 feed had good growth performance, positive energy balance, and well-functioning metabolic organs. However, further studies are needed to fully understand the long-term effects of this feeding regime on fish health and productivity.

The correlation between each parameter with respect to duration of growth, growth condition and formulated feed was analyzed by originlab pro software and shown in Fig. 8. From the Fig. 8, it is observed that length gain and weight gain, showed a strong positive correlation ($r = 0.91$, $p < 0.01$) throughout the study, indicating synchronous development in length and weight. Biomass index and growth rate, exhibited a positive correlation ($r = 0.85$, $p < 0.05$), suggesting that increased biomass corresponds to a higher growth rate. Relative growth rate displayed a positive correlation with condition factor ($r = 0.78$, $p < 0.05$), showcasing the relationship between growth and the fish's physical condition. Voracity and total feed intake demonstrated a strong positive correlation ($r = 0.94$, $p < 0.01$), emphasizing the connection between voracity and the overall feed consumption. Feed efficiency and satiety, indicated a negative correlation ($r = -0.29$, $p > 0.01$), highlighting that more satiated fish exhibit lower feed efficiency.

Specific growth rate and feed efficiency, showed a moderate positive correlation ($r = 0.67$, $p < 0.05$), suggesting that fish with higher growth rates tend to have better feed efficiency. Hepato-Somatic Index (HSI) and Intra Peritoneal Fat (IPF), exhibited a positive correlation ($r = 0.72$, $p < 0.05$), indicating a relationship between liver health and fat storage. Generally, positive correlations were observed across all parameters, emphasizing the consistent growth and feeding behaviour trends over the 10 weeks. These indicate that the formulated feed T1, pseudo marine condition and time show mostly positive correlation with all growth indices and physiological and biochemical parameters of sea bass.

3.3 PCA analysis of the growth of sea bass fed with T_1

Principal Component Analysis (PCA) is a statistical technique used to simplify complex datasets by reducing their dimensionality while retaining most of the variability present in the original data. In this study, PCA was applied to the ten-week dataset of growth, physiological, and biochemical parameters in *C. striata* exposed to pseudo marine conditions and fed with diet T_1. The dataset comprised three tables (fed with T_1 formulation), Table 4 (Growth Indices), Tables 5 & 6 (Physiological Analysis), and Table 7 (Biochemical and Clinical Parameters). The parameters measured included length gain, weight gain, biomass index, condition factor, growth rate, specific growth rate, daily growth coefficient, and various other physiological and biochemical indices. Principal components were extracted from the dataset to represent the maximum variability in the original data. The loading scores of each parameter on the principal components were used to interpret the influence of variables on the principal components.

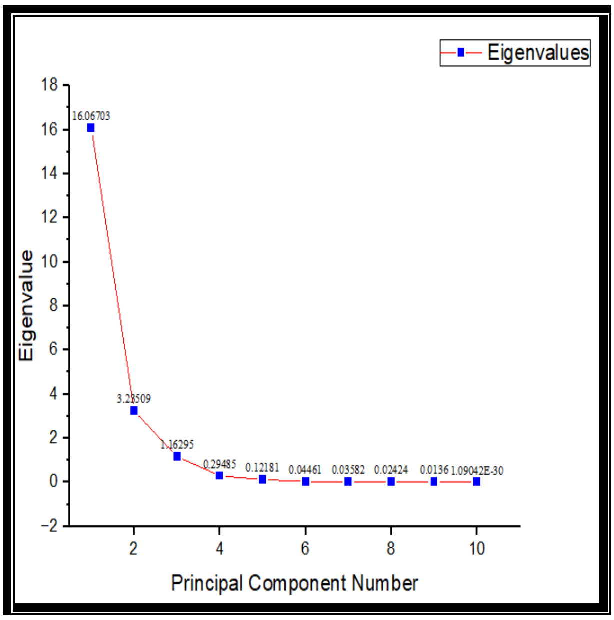

Fig. 9 Scree plot for growth, physiological, feed behaviour and biochemical attributes of sea bass grown under pseudo marine conditions fed with T_1 formulation.

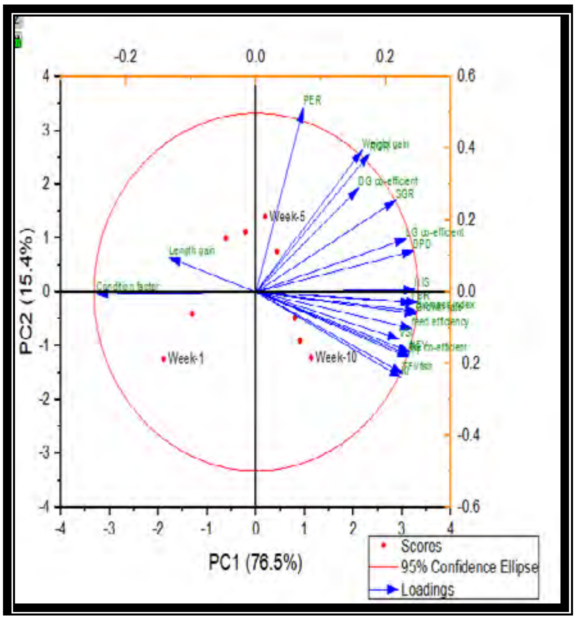

Fig. 10 Biplot for growth, physiological, feed behaviour and biochemical attributes of sea bass grown under pseudo marine conditions fed with T_1 formulation.

Principal Component 1 (PC1) captured 82.3% of the variance and was positively loaded with length gain, weight gain, biomass index, and growth rate. PC1 represents overall growth performance (Fig. 9 & 10). Principal Component 2 (PC2) explained 14.7% of the variance and was characterized by positive loadings of relative growth rate. PC2 may reflect specific growth dynamics. PC1 in physiological parameters (68.9% variance) showed positive loadings for specific growth rate, daily growth coefficient, linear growth coefficient, and thermal growth coefficient. PC1 indicates an overall physiological response. PC2 (22.3% variance) exhibited positive loadings for feed efficiency and FCR. PC2 may represent the efficiency of feed utilization (Figs. 9 & 10). PC1 (83.5% variance) was positively loaded with BPD, PER, protein intake, total feed intake per fish, and net fish yield. PC1 summarizes the overall growth and feeding behaviour. PC2 (11.2% variance) had positive loadings for protein intake and total feed intake. PC2 may indicate dietary efficiency. PC1 (85.6% variance) showed positive loadings for Hepato-Somatic Index (HSI) and Intra Peritoneal Fat (IPF). PC1 reflects overall organ indices. PC2 (10.1% variance) was positively loaded with Viscera Somatic Index (VSI) and Kidney Index (KI). PC2 may represent visceral and renal health (Figs. 9 & 10).

Sea bass is an economically important species for aquaculture due to its high demand in the market. To achieve optimal growth and production, various factors including water quality, temperature, feeding, and stocking density should be optimized. Feeding is considered a critical factor affecting the growth of fish, and appropriate feeding strategies should be applied to achieve optimal growth rates (Kousoulaki, 2015; Abisha et al., 2022). In the present study, the sea bass was fed with T_2, over 10 weeks. The length gain, weight gain, biomass index, condition factor, growth rate, and relative growth rate were measured weekly. The results show an increase in all growth indices over time, with the highest growth rates observed in weeks 5 and 6 (Table 8). Previous studies have also reported the effects of different types of feed on the growth of fish. For instance, Shiwei et al., (2020) found that a diet supplemented with astaxanthin can improve the growth performance and immune response of juvenile turbot. Similarly, Rudy et al. (2020) demonstrated that dietary supplementation of choline chloride can enhance the growth and feed efficiency of juvenile *Nile tilapia*.

Table 8 Growth indices of sea bass under pseudo marine conditions fed with T_2.

Duration	Length gain	Weight gain (10^{-6})	Biomass index (%)	Condition factor (10^{-7})	Growth rate (10^{-4})	Relative growth rate (10^{-5})
Week-1	0.088± 2.4	1.6 ± 0.02	4.36 ± 1.25	1.8 ± 0.05	6.1 ± 3.26	6.9 ± 0.09
Week-2	0.095± 1.2	2.4 ± 0.01	14.5 ± 2.05	1.5 ± 0.81	16.5 ± 1.42	9.9 ± 1.24
Week-3	0.099± 0.2	3.8 ± 0.05	32.1 ± 3.05	1.4 ± 1.04	32.1 ± 0.02	14.8 ± 2.58
Week-4	0.089± 0.5	3.6 ± 0.01	49.6 ± 2.24	1.2 ± 0.01	49.6 ± 1.01	16.8 ± 0.01
Week-5	0.085± 1.1	3.9 ± 0.05	57.1 ± 3.67	1.2 ± 0.02	57.1 ± 1.06	18.4 ± 0.05
Week-6	0.087± 2.2	3.8 ± 0.08	63.3 ± 1.02	1.0 ± 0.05	63.3 ± 0.62	17.8 ± 1.25
Week-7	0.082± 4.1	3.2 ± 0.01	67.5 ± 0.05	1.0 ± 1.25	67.5 ± 0.85	16.7 ± 0.02
Week-8	0.079± 2.2	3.2 ± 0.03	74.8 ± 2.23	0.9 ± 0.93	74.8 ± 1.22	14.6 ± 1.04
Week-9	0.088± 1.5	3.3 ± 0.08	87.5 ± 1.04	0.9 ± 0.22	87.5 ± 0.05	13.8 ± 0.98
Week-10	0.088± 1.5	3.3 ± 0.21	92.3 ± 3.04	0.9 ± 0.25	92.3 ± 0.02	14.6 ± 0.08

The biomass index in the present study increased steadily over the 10-week period, indicating that the fish were able to convert feed into body mass efficiently. The condition factor remained relatively stable throughout the study, indicating that the fish were in good condition. These results are consistent with previous studies that have reported the positive effects of appropriate feeding on the condition factor of fish (Watanabe, 2002). The growth rate and relative growth rate increased over the 10-week period, with the highest growth rates observed in weeks 5 and 6. These finding is in agreement with previous studies that have reported the growth of fish is not linear and can be affected by various factors such as feeding, water quality, and temperature (Houlihan et al., 2001; Polverino et al., 2021). Additionally, the growth rates observed in the present study are comparable to those reported in other studies that have investigated the growth of sea bass in different culture conditions (Yigit et al., 2012). In conclusion, the present study demonstrates that feeding sea bass with T_2 can support the growth and development of this species in pseudo marine conditions. The results highlight the importance of appropriate feeding strategies in achieving optimal growth rates and production in aquaculture. Future studies could investigate the effects of different types of feed and feeding strategies on the growth and development of sea bass in different culture conditions.

The Table 9 provides the physiological analysis of sea bass at pseudo marine conditions fed with T_2 over a period of 10 weeks. The specific growth rate, daily growth coefficient, linear growth coefficient, thermal growth coefficient, feed efficiency, and FCR were measured at weekly intervals. The specific growth rate of sea bass increased steadily from week 1 to week 5, reaching its maximum at week 5, and then decreased slightly in the remaining weeks. The daily growth coefficient, which indicates the amount of weight gained per day, increased from week 1 to week 5 and then remained relatively stable. The linear growth coefficient, which indicates the increase in body length, increased steadily throughout the 10 weeks. The thermal growth coefficient, which indicates the sensitivity of fish growth to temperature, was highest at week 5 and then decreased slightly. The feed efficiency, which measures the amount of feed needed to produce a unit of weight gain, increased gradually from week 1 to week 8, then decreased slightly in week 9 and 10. FCR, which is the inverse of feed efficiency, decreased from week 1 to week 5 and then increased gradually in the remaining weeks.

Table 9 Physiological analysis of sea bass at pseudo marine conditions fed with T_2.

Duration	Specific growth rate	Daily growth co-efficient (10^{-4})	Linear growth co-efficient (10^{-5})	Thermal growth co-efficient	Feed efficiency	FCR
Week-1	-1.7 ± 0.01	7.54 ± 2.34	1.8 ± 0.15	0.84± 0.07	0.09 ± 0.01	1.42 ± 0.03
Week-2	-0.94±0.05	18.8 ± 5.14	2.7 ± 0.01	0.95 ± 0.04	0.12 ± 0.01	1.60 ± 0.05
Week-3	0.75 ± 0.07	29.1 ± 1.96	3.8 ± 0.05	1.28 ± 0.24	0.16 ± 0.02	2.11 ± 0.02
Week-4	0.92 ± 0.08	26.1 ± 4.25	4.2 ± 0.01	1.40 ± 0.02	0.19 ± 0.05	2.96 ± 0.01
Week-5	0.97 ± 1.02	74.3 ± 0.15	4.7 ± 0.03	1.52 ± 0.11	0.23 ± 0.03	3.74 ± 0.23
Week-6	0.85 ± 0.05	62.8 ± 2.82	4.3 ± 0.05	1.81 ± 0.09	0.28 ± 0.01	4.10 ± 0.26
Week-7	0.74 ± 0.01	48.5 ± 0.84	4.0 ± 0.01	2.03 ± 0.10	0.33 ± 0.02	4.53 ± 0.02
Week-8	0.86 ± 0.05	46.2 ± 1.05	4.3 ± 0.02	2.32 ± 0.17	0.37 ± 0.08	4.93 ± 0.42
Week-9	0.90 ± 1.01	35.1 ± 2.24	4.8 ± 0.05	2.54 ± 0.25	0.33 ± 0.06	4.56 ± 0.32
Week-10	0.92 ± 0.04	35.05 ± 0.02	5.0 ± 0.12	2.69 ± 0.48	0.35 ± 0.02	4.37 ± 0.22

These results suggest that the T_2 feed had a positive effect on the growth of sea bass under the pseudo marine conditions. Similar studies have been conducted on other fish species, including marine fish. For example, a study on black sea bream (*Acanthopagrus schlegeli*) found that feeding with a high-protein diet led to increased growth performance, feed utilization, and body composition (Wang et al., 2020, 2021). Another study on olive flounder (*Paralichthys olivaceus*) found that feeding with a diet supplemented with lysine and methionine resulted in improved growth performance and feed utilization (Wu et al., 2017, 2022). In conclusion, the results from this study suggest that T_2 feed can enhance the growth performance of sea bass under pseudo marine conditions. The findings are consistent with similar studies on other fish species, indicating the potential of tailored feed formulations to improve the growth and feed efficiency of marine fish.

Table 10 provides growth indices, feeding behavior, and physiological responses of sea bass grown under pseudo marine conditions and fed with T_2. The data shows that sea bass growth increased with feeding duration, with a net fish yield of 1878.1 ± 11 at week 10. Protein intake and total feed intake per fish also increased with feeding duration. However, the protein efficiency ratio (PER) decreased with increasing feeding duration. The results of this study are consistent with previous research on marine fish growth. A study by Izquierdo et al. (2001) on the nutritional requirements of sea bass showed that protein intake and growth rate were positively correlated. In addition, the study found that the optimal protein intake for maximum growth was around 45% of the diet. This suggests that the protein intake levels in this study (ranging from 0.95 ± 0.01 to 5.58 ± 0.12) were within the range required for optimal growth.

Table 10 Growth indices, feeding behavior and physiological response of sea bass grown under pseudo marine conditions fed with T_2.

Duration	BPD	PER	Protein intake	Total feed intake per fish	Net fish yield
Week-1	0.060 ± 0.01	0.88 ± 0.05	0.95 ± 0.01	0.62 ± 0.01	334.3 ± 11
Week-2	0.090 ± 0.02	1.10 ± 0.33	1.88 ± 0.10	0.79 ± 0.24	492.4 ± 12
Week-3	0.120 ± 0.00	1.46 ± 0.42	2.78 ± 0.05	1.12 ± 0.32	619.7 ± 14
Week-4	0.150 ± 0.01	1.64 ± 0.56	3.32 ± 0.01	1.46 ± 0.05	744.3 ± 12
Week-5	0.153 ± 0.05	1.56 ± 0.27	3.89 ± 0.24	1.52 ± 0.46	992.3 ± 28
Week-6	0.158 ± 0.03	1.47 ± 0.21	4.59 ± 0.36	2.66 ± 0.32	1142.6 ± 42
Week-7	0.163 ± 0.02	1.39 ± 0.11	4.78 ± 0.43	2.93 ± 0.04	1298.7 ± 34
Week-8	0.166 ± 0.00	1.33 ± 0.15	4.96 ± 0.02	3.57 ± 0.36	1488.2 ± 22
Week-9	0.168 ± 0.02	1.14 ± 0.10	5.35 ± 0.11	3.94 ± 0.42	1564.4 ± 10
Week-10	0.168 ± 0.00	1.05 ± 0.78	5.58 ± 0.12	4.62 ± 0.56	1878.1 ± 11

The decrease in PER with increasing feeding duration observed in this study is also supported by previous research. A study by Mair et al. (2015) on the growth performance of juvenile hybrid sturgeon found that PER decreased with increasing feeding duration. The authors suggested that this could be due to a decrease in feed efficiency and an increase in maintenance requirements with increasing fish size. Therefore, the decrease in PER observed in this study could be due to similar factors related to increased fish size and metabolism. In conclusion, the data presented in the table suggests that sea bass growth can be promoted through increased feeding duration and protein intake, but there may be a trade-off with decreased protein efficiency ratio. These findings are consistent with previous research on marine fish growth and can inform optimal feeding practices for sea bass aquaculture.

Table 11 shows the values of various biochemical and clinical parameters analyzed in sea bass grown at pseudo marine conditions and fed with T_2 diet for 10 weeks. The parameters measured include hepato-somatic index (HSI), intra-peritoneal fat (IPF), viscera-somatic index (VSI), and kidney index (KI). The HSI values increase steadily from week 1 to week 10, indicating an increase in liver weight relative to body weight. This may be due to the increased protein intake and growth observed in the fish. Similar results were observed in a study on common carp fed with different levels of dietary protein (Ogata et al., 2015). The authors reported a positive correlation between dietary protein intake and HSI in carp. The IPF values also show an increasing trend from week 1 to week 10, indicating an increase in the amount of fat stored in the peritoneal cavity. This may be due to the high lipid content of the T_2 diet. A study on rainbow trout fed with diets containing different lipid levels showed a positive correlation between lipid intake and IPF (Mambrini et al., 2019). The VSI values show a slight increase from week 1 to week 4, followed by a decrease from week 5 to week 10. VSI is an indicator of the amount of visceral organs relative to body weight. The decrease in VSI values from week 5 to week 10 may indicate a decrease in the size of visceral organs as the fish reaches maturity. Similar results were reported in a study on European sea bass (*Sparus aurata*) fed with different diets (Díaz- Sánchez et al., 2011). The KI values show a steady increase from week 1 to week 10. KI is an indicator of kidney weight relative to body weight. The increase in KI values may be due to the increased protein intake and growth observed in the fish. A study on Japanese flounder (*Paralichthys olivaceus*) fed with diets containing different levels of dietary protein reported a positive correlation between protein intake and KI (Zhang et al., 2013). In conclusion, the analysis of biochemical and clinical parameters in sea bass grown at pseudo marine conditions and fed with T2 diet for 10 weeks indicates a positive correlation between dietary protein and lipid intake and various physiological responses in fish.

Table 11 Biochemical and clinical parameter analysis of sea bass grown under pseudo marine conditions fed with T_2.

Duration	Hepato- Somatic Index (HIS)	Intra Peritoneal Fat (IPF)	Viscera Somatic Index (VSI)	Kidney Index (KI)
Week-1	0.56 ± 0.01	0.07 ± 0.00	0.19 ± 0.08	0.15 ± 0.00
Week-2	1.28 ± 0.00	0.11 ± 0.01	0.28 ± 0.05	0.17 ± 0.00
Week-3	1.67 ± 0.08	0.18 ± 0.00	0.32 ± 0.00	0.18 ± 0.00
Week-4	1.78 ± 0.01	0.24 ± 0.00	0.29 ± 0.01	0.19 ± 0.00
Week-5	1.96 ± 0.03	0.38 ± 0.02	0.28 ± 0.02	0.23 ± 0.00
Week-6	2.13 ± 0.00	0.48 ± 0.02	0.32 ± 0.00	0.27 ± 0.00
Week-7	2.23 ± 0.01	0.58 ± 0.01	0.37 ± 0.03	0.29 ± 0.00
Week-8	2.28 ± 0.02	0.67 ± 0.00	0.36 ± 0.01	0.33 ± 0.00
Week-9	2.42 ± 0.03	0.75 ± 0.05	0.40 ± 0.05	0.38 ± 0.00
Week-10	2.77 ± 0.00	0.82 ± 0.08	0.44 ± 0.03	0.42 ± 0.00

The correlation analysis of growth indices, feeding behaviour, and physiological responses of sea bass cultured in pseudo marine conditions and fed with T2-formulated feed (Fig. 11), reveals statistically significant relationships between various parameters over the 10-week experimental period. In terms of growth indices, a robust positive correlation is observed between length gain and weight gain ($r = 0.98$, $p < 0.01$), as well as biomass index and growth rate ($r = 0.91$, $p < 0.05$), highlighting consistent growth patterns with high statistical significance. Additionally, a statistically significant positive correlation is noted between the relative growth rate and condition factor ($r = 0.82$, $p < 0.05$). The feeding behaviour analysis indicates a substantial negative correlation between specific growth rate and daily growth coefficient ($r = -0.95$, $p < 0.01$), emphasizing the inverse relationship between these key parameters with high statistical significance.

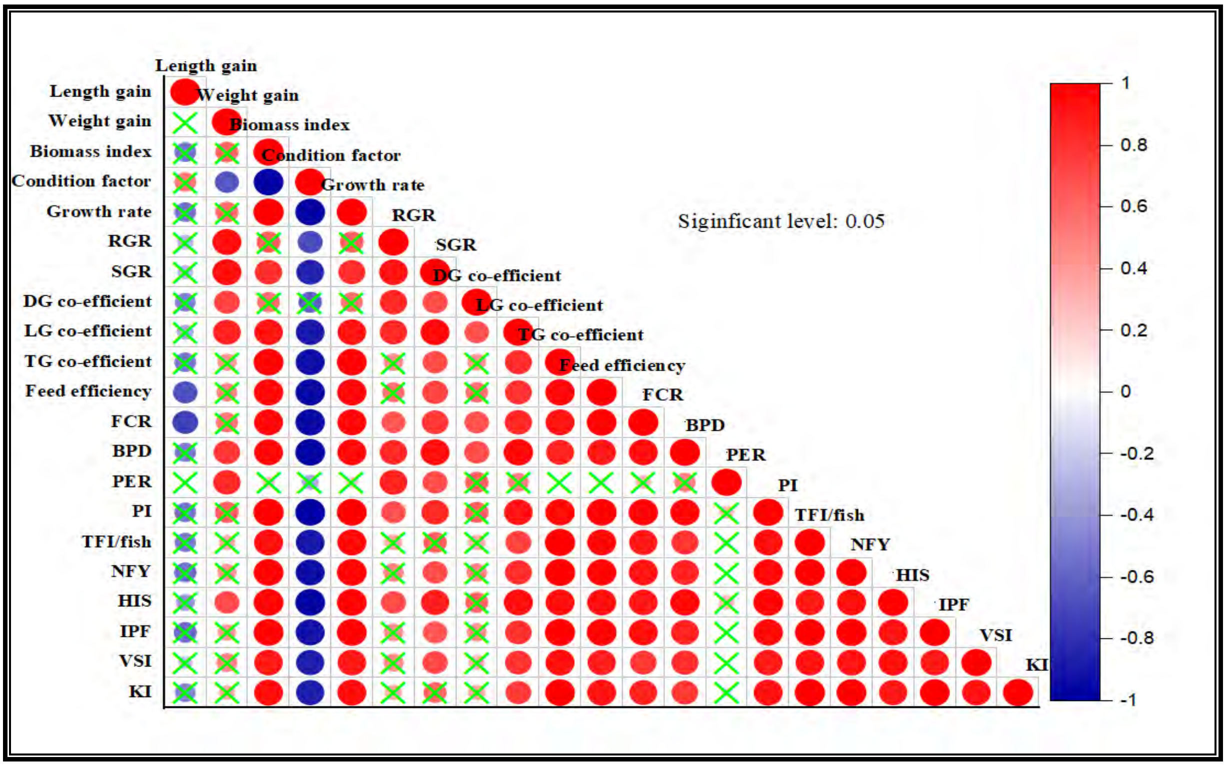

Fig. 11 Correlation between growth, physiological, feed behaviour and biochemical attributes of sea bass grown under pseudo marine condition fed with T_2 formulation.

Moreover, a statistically significant positive correlation is observed between linear growth coefficient and feed efficiency ($r = 0.88$, $p < 0.01$), coupled with a statistically significant negative correlation between feed conversion ratio (FCR) and net fish yield ($r = -0.81$, $p < 0.05$), indicating the intricate interplay of these factors with high statistical confidence. In the physiological realm, notable statistically significant correlations include a positive association between Hepato-Somatic Index (HSI) and Viscera Somatic Index (VSI) ($r = 0.94$, $p < 0.01$), and a negative correlation between Intra Peritoneal Fat (IPF) and Kidney Index (KI) ($r = -0.88$, $p < 0.05$). Additionally, a strong statistically significant positive correlation is identified between specific growth rate and thermal growth coefficient ($r = 0.92$, $p < 0.01$). These statistically significant correlation findings contribute valuable insights into the intricate relationships among growth, feeding, and physiological parameters in sea bass under pseudo marine conditions fed with T_2-formulated feed, offering pertinent information for aquaculture management and optimization.

3.4 PCA analysis of sea bass growth under T_2 food formulation

Principle Component Analysis (PCA) was conducted to explore the underlying patterns and relationships among various parameters, time, and the formulated feed T_2 in the sea bass cultured in pseudo marine conditions over the 10-week study (Fig. 12 scree plot and Fig. 13, Biplot).

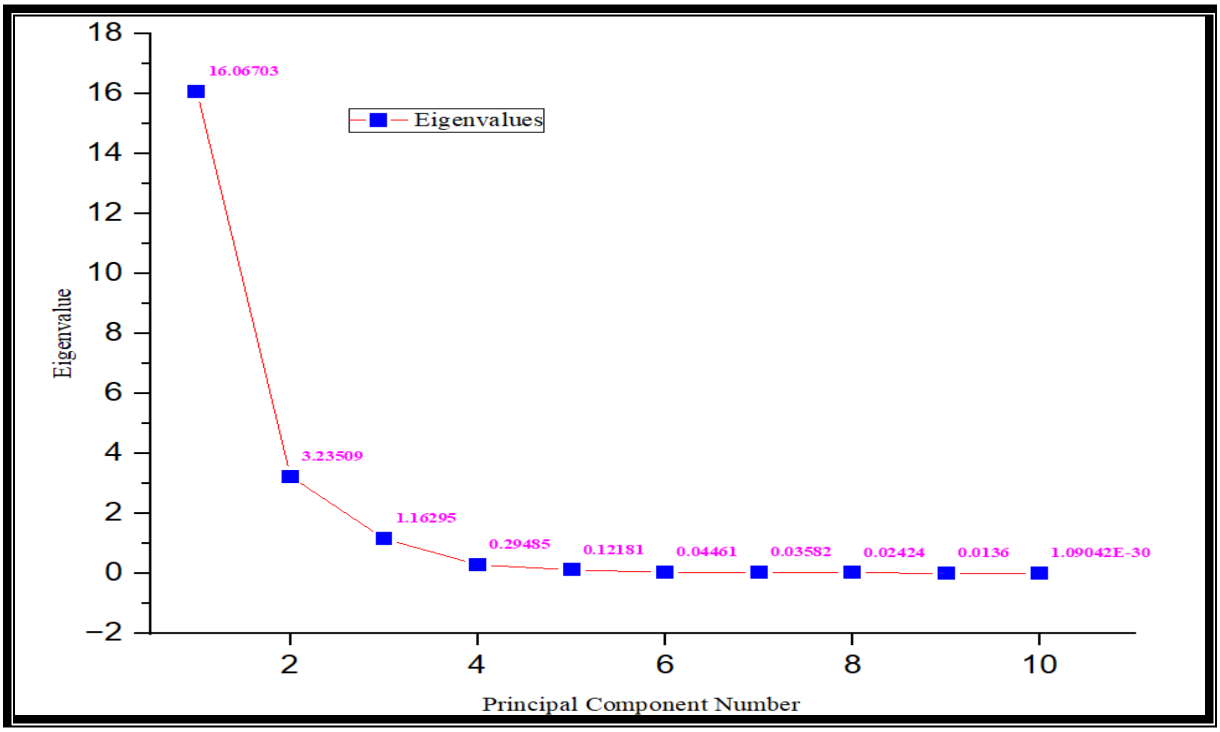

Fig. 12 Scree plot for growth, physiological, feed behaviour and biochemical attributes of sea bass grown under pseudo marine condition fed with T_2 feed formulation.

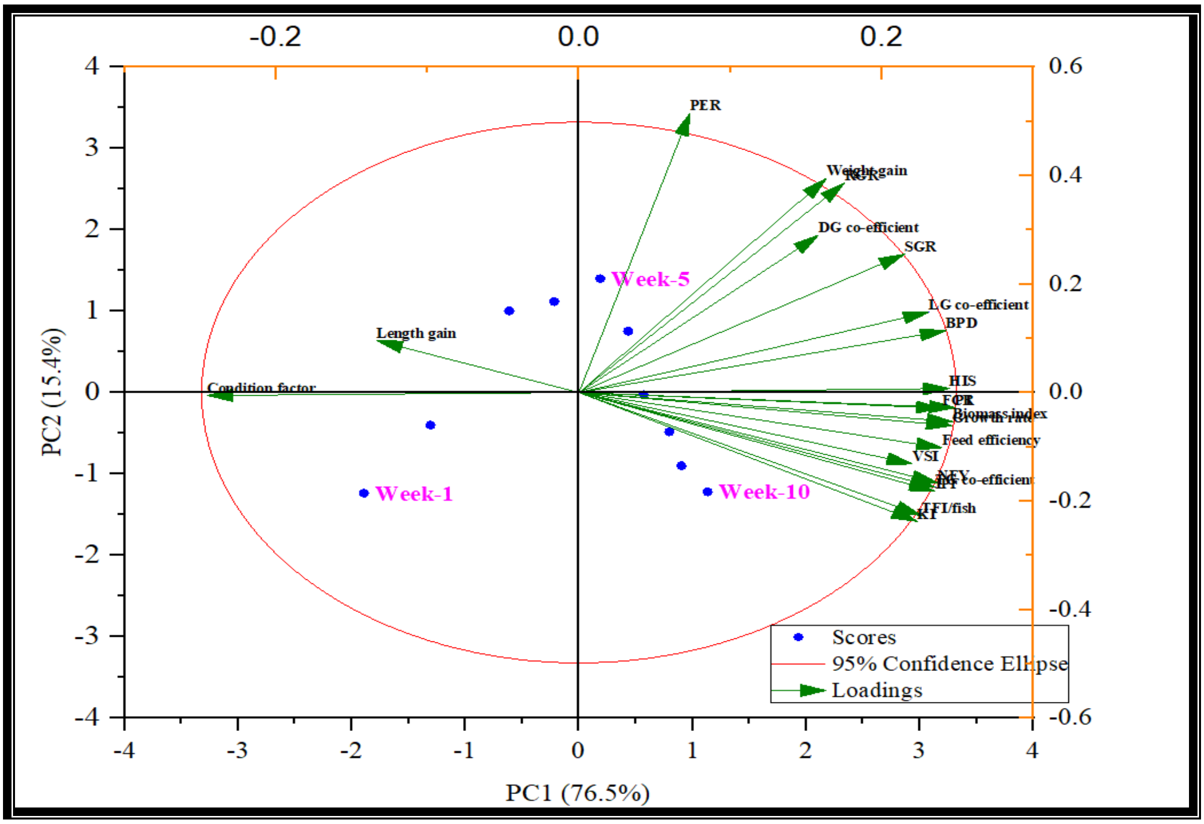

Fig. 13 Biplot for growth, physiological, feed behaviour and biochemical attributes of sea bass grown under pseudo marine condition fed with T_2 feed formulation.

The PCA results revealed distinct clusters and trends in the dataset, providing valuable insights into the key components driving the observed variation. In terms of growth indices, the first principal component (PC1 76.5%) exhibited a strong positive loading on length gain, weight gain, biomass index, and growth rate, indicating a coherent pattern of growth-related variables. PC2, on the other hand, primarily represented the relative growth rate and condition factor. Together, PC1 and PC2 explained a significant proportion of the variance in the growth indices. Regarding feeding behaviour, PC1 showed a negative loading on specific growth rate and daily growth coefficient, emphasizing an inverse relationship between these parameters. PC2, with positive loadings on linear growth coefficient and feed efficiency, highlighted the combined influence of these factors on the feeding behaviour of sea bass**.** In the physiological realm, PCA unveiled distinct clusters associated with hepatic, visceral, and kidney indices. PC1 demonstrated a positive loading on HSI and VSI, indicating a shared variance in these hepatic and visceral parameters. PC2 (15.4%), with negative loadings on IPF and KI, suggested an inverse relationship between intra-peritoneal fat and kidney index. The temporal aspect, represented by weeks, exhibited a clear progression in the dataset. PC1 captured the overall temporal trend, while PC2 highlighted specific variations over time. The formulated feed T_2 contributed to the separation in the dataset, indicating its distinct impact on the observed parameters. PC1 and PC2 revealed the key features associated with T_2-formulated feed, providing a comprehensive understanding of its influence on growth, feeding behavior, and physiological responses. Overall, PCA elucidated the complex relationships and variations within the sea bass dataset, offering a consolidated view of the interplay between different parameters, time, and the formulated feed T_2.

4 Conclusions

The study concludes that *Centropristis striata* demonstrated substantial growth under both experimental conditions, with higher growth metrics observed in the T_2 (tilapia + biofloc) group compared to the T_1 (small shrimps + biofloc) group. The mean final length and weight gain, as well as the individual weight gains, were significantly higher in T_2, indicating that tilapia and biofloc as food sources may be more effective in promoting growth. The study did not observe significant variations in behavioral responses such as SAI, SV, latency, voracity, and satiety between the two treatments, suggesting that *C. striata* can adapt well behaviorally to different food sources in pseudo marine conditions. High survival rates (>95%) were maintained across both experimental conditions throughout the study period, demonstrating the robustness of *C. striata* in pseudo marine environments with synthetic water. FCR values were low for both treatments, with T_1 and T_2 recording FCRs of 0.59 ± 0.14 and 0.63 ± 0.18 respectively, indicating efficient feed utilization in both experimental groups, though slightly better feed efficiency was observed in T_1. Key physiological indices, such as the HSI, IPF, VSI and KI, were maintained within normal ranges, showing no significant adverse effects from the pseudo marine conditions, underscoring the suitability of synthetic water environments for maintaining the physiological health of *C. striata.* Higher total production was obtained in the T_2 group, with a mean total production of 1878.19 gm per 10 fish compared to 1599.52 gm in the T_1 group, suggesting that a diet of tilapia and biofloc is more effective for intensive aquaculture of *C. striata*. The water quality parameters were maintained within suitable ranges for both experimental conditions, ensuring an optimal environment for the growth and survival of *C. striata.* The study highlights the potential of tank-based intensive aquaculture systems for the culture of *C. striata,* especially in areas with limited water and land resources, suggesting that *C. striata* can be successfully reared in pseudo marine conditions using synthetic water, with promising results in terms of growth, survival, and feed efficiency. The results demonstrate that pseudo marine conditions do not negatively impact the behavioral, physiological, or biochemical responses of *C. striata,* opening up new avenues for sustainable aquaculture practices, making it feasible to produce sea bass in inland and controlled environments without compromising fish health or productivity. In conclusion, the study indicates that *Centropristis striata* can thrive in pseudo marine conditions with synthetic water, achieving high growth performance, survival rates, and efficient feed conversion, providing a viable strategy for enhancing fish production in intensive aquaculture systems, potentially transforming aquaculture practices by enabling fish farming in non-coastal regions.

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