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RESEARCH

Commercial Shrimp Feed Usage as Guppy (*Poecilia reticulata*) Fry Feed: Effect for Growth Performance, Liver Histology, Pigmentation, and Stress Tolerance

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ABSTRACT

Purpose: *Species-specific aquafeed confirms better results in commercial aquaculture, providing optimized nutrition for each species. However, cost-effective shrimp feeds are frequently used in the ornamental fish industry due to their benefits, such as growth and pigmentation enhancement. These facts were not tested, and therefore, this experiment was conducted to fill a research gap and explore the effectiveness of shrimp feed.*

Research Method: *A commercial fish feed was used as the control (FF) at 3% of body weight (BW) and with a feeding frequency of 2 times/day. Fish were fed the shrimp feed (SF) at 3%BW and 2/day (SF(3.2)), 3%BW and 4/day (SF(3.4)), 6%BW and 2/day (SF(6.2)), and 6%BW and 4/day (SF(6.4)).*

Findings and Values: *The SF(6.4) and SF(6.2) fish groups achieved the highest growth performance compared with the control. Regression analysis curves proved that the growth performance of the SF(6.4) group was higher than that of the SF(6.2) group. Moreover, the SF(3.4) group achieved higher growth than the control, whereas the SF(3.2) group showed no statistically difference in growth compared with the control. All the SF-fed groups gained a higher colour intensity than the control. The SF feeding did not adversely affect the stress tolerance or survival of the fish. Shrimp feed effectively gains the weight and pigmentation of ornamental fish. However, feeding frequency and rate should be controlled to avoid hepatic alterations.*

Keywords: *Aquafeed, Colour intensity, Fatty liver, Sustainable feed*

INTRODUCTION

Aquafeeds play a dominant role in aquaculture as commercial production intensifies. Profitability and the sustainability of the industry depend heavily on the cost-effectiveness of feeds and their optimum nutrient quality (Patra &Tripathy 2022). Therefore, species-specific aquafeeds are ideal for any fish species because they have been formulated to meet the nutrient requirements of the relevant aquatic species, ensure ingredient sustainability, and maintain feed quality. Moreover, species-specific feeds satisfy the enhanced demands of commercial aquaculture and food safety (Joshi *et al*. 2021).

The ornamental fish industry is a vital

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component of global commercial aquaculture. Its market value was 5.42 USD billion in 2019, and it is projected that the value of this aqua business will expand to 11.68 USD billion by 2031 with an annual growth rate of 8.5 (Tandel *et al*. 2024). There has been little information available on the nutritional requirements of different ornamental fish species (Tamaru & Ako 1999). The prices of ornamental fish feeds are 10-60 times higher, and prices are also soaring compared to general food fish feed (Tamaru & Ako 1999). Further, some countries have a significant gap between the demand and supply of ornamental fish feed (Parappurathu *et al*. 2021). Therefore, ornamental fish farmers have inclined towards non-specific aqua feeds such as shrimp feeds, food fish feed, and seabass feeds.

The liver in fish plays a primary role in digesting food and assimilating nutrients into the body; accordingly, it is vital to monitor the functioning of these organs to ensure optimal fish wellbeing (Roberts 1989, Takashima & Hibiya 1995). Therefore, it is susceptible to histological alterations in the liver when the diet is poorly formulated. (Tacon 1992). Nutrition-based fatty liver in fish significantly impedes the long-term viability of the aquaculture industry, primarily driven by high-energy feeds oversupplied with fats and starches, coupled with deficiencies in vital micronutrients. (Zhao *et al*. 2023). Lu *et al*. (2014) determined that the above condition in fish contributed to several adverse outcomes, including oxidative stress, liver damage, decreased growth, and increased mortality.

Commercial shrimp feeds have been widely used as ornamental fish feeds owing to their greater availability, lower prices, and higher growth performance. Simultaneously, extensive use of shrimp feed has led to issues with ornamental fish, as the farmers mentioned. These identified issues include fatty liver in fish, shorter lifespans, and low-quality brooders. The above suggestions have been confirmed through random sample testing of dissected fish before export by the exporters (visual observation of liver colour change and microscopic observation of liver fat globules) and buyers' reports (U Wickramasinghe, Consultant, Haritha Fish Farm, Bope, Padukka, Sri Lanka, Personnel communication, November 20, 2025).

Guppy *Poecilia reticulata* is a demanded ornamental fish cultured in Asian countries (Chong *et al*. 2004). Previous experiments achieved comparable or better performance by feeding formulated feeds to the fry stage of *P. reticulata* than *Artemia-fed fish* (Sahin *et al*. 2012, Perera *et al*. 2022). However, formulated fish feeding has created health issues in this fish, such as fatty liver (Sharon *et al*. 2014, Perera *et al*. 2025). The above issues have not been investigated; therefore, this experiment was carried out to identify the effects of shrimp feed on growth, pigmentation, stress tolerance, and hepatic alterations in *P. reticulata* fry.

MATERIALS AND METHODS

This experiment was conducted in the indoor aquarium at the Regional Research Center, Panapitiya, Waskaduwa, of the National Aquatic Resources Research and Development Agency (NARA), Sri Lanka.

Purchasing P. reticulata fry and conditioning

A total of 500 *P. reticulata* male fry of the Golden Tuxedo strain were procured from Deepika Fish Farm, Handapangoda, Sri Lanka. All the fish were conditioned for a week before the experiment was initiated. The fish were stocked in glass tanks, each with a capacity of 82 L, and were hand-fed to the maximum satiation level twice daily, with the control feed containing (44.4±0.4%) crude protein. Water quality parameters were maintained within the optimum ranges, including total ammoniacal nitrogen, pH, and dissolved oxygen.

Setting up the glass tanks for the experiment

Fifteen glass tanks, mentioned above, were used to stock the fish. Water aeration was provided by a RESUN GF-750 air compressor (Guangzhou Puyangli Aquarium & Accessories Co. Ltd, Guangdong, China). The water level was maintained at a depth of 30 cm in each tank. Air temperature and light intensity were detected using an AS 803 Smart Sensor lux meter (ARCO, Dong Guan, China) and regulated to 27.4±1.0 °C and 823±41 Lux, respectively. The photoperiod was set to 12 hours (light)/12 hours (dark) using LED bulbs. The experiment followed a completely randomized design (CRD) with five treatments (Fish feed (control) (FF), Shrimp feed fed with 3% of the body weight of the fish 2 times daily (SF3.2), Shrimp feed fed with 3% of the body weight of the fish 4 times daily (SF3.4), Shrimp feed fed with 6% of the body weight of the fish 2 times daily (SF6.2), Shrimp feed fed with 6% of the body weight of the fish 4 times daily (SF6.4)), each replicated three times.

Experimental diets

A tropical fish feed (crude protein; 44.4±0.4, crude lipid; 7.0±0.40) was used as the control diet, and a commercial shrimp feed (crude protein; 43.1±0.10, crude lipid; 6.6±0.45) was utilized as the research diet. The proximate composition of the feeds has been mentioned in Table 1.

Testing the proximate composition and the energy of the feeds

The proximate composition of the commercial feeds was analyzed following the AOAC (1990) protocol at the laboratory of Ceylon Grain Elevators, Colombo 15. Sri Lanka. The energy was tested at the Palmyrah Research Institute, Jaffna, Sri Lanka, with the e2K Combustion Calorimeter (Digital Data Systems (Pvt) Ltd, Gauteng, South Africa).

Stocking and rearing the fish

A total of 450 fish were randomly selected for the experiment from the conditioned fish stock, 30 fish per tank (average size of 5.4±0.8 mg). The feeding rate and feeding frequency of the diets were maintained according to Table 2. A total of five fish from each replicate were sampled weekly, and the body weights of the fish were measured using the OHAUS PIONEER PA 214C digital balance (OHAUS, Parsippany, USA). The feed budget was adjusted weekly, calculating the measured weights of the fish samples.

Water quality management

Each tank was siphoned out twice daily, and the removed water was replaced with conditioned water at a 30 cm level. Once a week, two-thirds of the water volume in each tank was removed and replenished with the conditioned water. Dissolved oxygen (DO) levels were monitored daily using the EZDO PDO-408 Dissolved Oxygen Meter (Gon DO Electronic Co. Ltd, Taipei City, Taiwan), and pH was recorded with the EUTECH pH 150 meter (Thermo Fisher Scientific Eutech, Singapore). Ammonia concentration was tested weekly using a commercial test kit (NT Laboratories Ltd, Kent, TN 12 9QS, UK).

The WTW Cond 3310 Conductivity Meter (Xylem Analytics GmbH & Company, Weinheim, Germany) measured conductivity and water temperature. The water quality parameters were maintained as (average±SE): DO 6.52±0.10 mg·L^{-1}, pH 7.73±0.02, total ammonia nitrogen 0.3±0.0 mg·L^{-1}, conductivity 117.0±3.2 μs/cm, and water temperature 26.4±0.0 °C).

Testing the growth performance

After seventy days (ten weeks) of rearing, the fish's body weight was measured using the above digital balance. Survival rate and growth performance were calculated using the following equations.

$$\text{Survival rate} = \frac{\text{Final fish number}}{\text{Initial fish number}} \times 100 \quad (1)$$

$$\text{Weight gain (WG)} = \text{Final weight (g)} - \text{Initial weight (g)} \quad (2)$$

$$\text{Daily weight gain (DWG)} = \frac{\text{Weight gain (g)}}{\text{Number of days}} \quad (3)$$

$$\text{Relative weight gain (RWG)} = \left(\frac{\text{Weight gain (g)}}{\text{Initial weight (g)}}\right) \times 100 \quad (4)$$

Table 1. The proximate composition of the control feed and commercial shrimp feed. FF- Fish Feed (control), SF- shrimp feed.

Parameter	FF (%)	SF (%)	P value
Dry matter content	90.5±0.55	90.7±0.75	0.92
Crude protein	44.4±0.40	43.1±0.10	0.08
Crude lipid	7.0±0.40	6.6±0.45	0.53
Moisture	9.5±0.35	10.3±0.40	0.29
Ash	9.8±0.15[a]	12.6±0.30[b]	0.01
Fiber	2.4±0.30	3.6±0.10	0.09
NFE	36.4±0.20	34.1±0.35	0.05
Energy (Kcal/g)	3.92±0.35	4.03±0.15	0.82

Table 2. Feeding Rate and Feeding Frequency of the Treatment Diets. FF- Fish Feed (control), SF- shrimp feed.

Treatment	Feeding Rate (%)	Feeding Frequency
FF	3	2
SF(3.2)	3	2
SF(3.4)	3	4
SF(6.2)	6	2
SF(6.4)	6	4

$$\text{Specific growth rate (SGR)} = \frac{\ln(\text{final weight}) - \ln(\text{initial weight})}{\text{number of days}} \times 100 \quad (5)$$

Testing the liver histology and the grading process

The liver histology of the fish was analyzed following the guidelines of the National Society for Histotechnology (NSH (2007)) and Gobinath & Ramanibai (2014) protocol. A total of three fish in each tank were randomly selected, and the fish were euthanized using 150 mg/L clove oil (Cunha *et al*. 2015). The fish livers were dissected from each replicate. The liver samples were kept in tagged vials and fixed for 24 hours after being preserved in 10% neutral buffered formalin. The histopathological analysis was conducted at the Department of Veterinary Pathobiology, University of Peradeniya, Sri Lanka. Then, the fixed liver tissue samples were washed with distilled water and kept in the carrier of the automatic tissue processor SE 400 (Shandon Scientific Co. Ltd, England). The samples were dehydrated in different grades of alcohol series (70%, 80%, and 90% ethanol and three absolute alcohol baths).

The embedding process was done in the TEC 2900 embedding machine (Histo-Line Laboratories, Italy) and cooled in the TEC 2900 cold chamber (Histo-Line Laboratories, Italy) for five minutes to enable the removal of the block from the mould. The section cutting was done using the 4 μm microtome (Histo-Line Laboratories, Italy). The staining was done through hydration, followed by dehydration. Xylene was used to remove the wax. The hydration process was done using the descending sequence of alcohol. Hematoxylin and eosin staining was followed to conduct the histopathological analysis (NSH 2007). Subsequently, it was mounted using DPX and observed using a Euromex iSscope microscope (Euromex Microscopes, Arnhem, Netherlands) at the magnification $\times10\times4$.

The hemocytes were graded by a panel of three individuals, aiming to analyze the fatty liver and steatohepatitis. The observations were recorded using an Olympus CX 43 biological microscope (Olympus Corporation, Japan). The liver samples were graded from “0 to +3” with no abnormality, mild, moderate, and severe, respectively.

Pigmentation analysis

A total of five fish from each replicate were anaesthetized with 125 mg/l clove oil as Cunha *et al*. (2015) recommended. The caudal fins of each fish were photographed on a white background, with a Nikon D7500 DSLR camera (Nikon Imaging Inc., Tokyo, Japan) and a YONGNUO YN 60 mm macro lens (YONGNUO, Shenzhen, China). The light intensity was maintained at 824±31 Lux at 28.9±2.0 °C. The photography was carried out following the guidelines of Stevens *et al*. (2007). The shutter speed and aperture were 1/40 and 8, respectively, while the ISO number was 320. A place with ample lighting was selected, and a spotlight was used. The digital images were analyzed using the MATLAB program, and they were converted to greyscale, where the pixel values ranged from 0 (black) to 255 (white). Lower values indicated higher pigmentation (Uribe *et al*. 2018).

Stress tolerance test

The methodology used by Lim *et al*. (2003) was followed to conduct the stress tolerance test. Ten fish were randomly selected from each replicate and were dipped in pre-aerated 500 ml beakers filled with 30 ppt water. The mortality of the fish was documented every 3 minutes over a two-hour period, and the stress tolerance index was calculated based on total and early mortality.

Statistical analysis

Growth performance, survival, colour intensity, and stress tolerance data were compiled in MS Excel and analyzed using one-way ANOVA followed by mean comparisons using Tukey’s test. Prior to the analyses, normality and homogeneity of the variance were confirmed using the Levene test. Diets were compared using two-way ANOVA followed by Tukey’s test. Regression analysis was done to see the relationship between weight and time. SPSS software version 22.0 was used for all analyses, and results were considered significant at $p<0.05$, with means expressed as mean ± standard error.

RESULTS AND DISCUSSION

Growth performance

The regression analysis and growth performance results for *P. reticulata* fed different treatment diets are shown in Fig. 1 and Table 3.

The fish well ingested all the experimental diets, and Fig. 1 confirmed that the growth performance of fish fed shrimp feed was higher than that of fish fed fish feed. Table 3 further confirmed that shrimp feed-fed fish showed higher growth except for SF(3.2) regarding final weight, WG, DWG, RWG, and SGR. Fish fed 6% shrimp feed exhibited higher growth performance than those fed 3% shrimp feed, and feeding frequency did not affect performance. However, the control feed and SF(3.2) did not show any statistical difference ($p<0.05$) in the above parameters, whereas SF(3.4) and the control showed significant differences ($p<0.05$). The SGR values of all the shrimp feed-fed fish groups, except SF(3.2), were statistically higher than those of the control feed-fed fish group. Survival is independent of all the feed types.

Liver histology of the fish

As far as the results of grading of liver tissues from the five treatments are concerned, no histopathological changes were observed in the control (FF) group; tissues were compact and there showed no vacuoles. The SF(3.2) treatment indicated a moderate fatty liver condition, whereas SF(3.4), SF(6.2), and SF(6.4) indicated a severe fatty liver condition, as per the grading results (Fig. 2, Table 4).

The fatty liver variation was as follows: FF < SF(3.2) < SF(3.4) = SF(6.2) = SF(6.4)

Pigmentation of fish

All the shrimp feed-fed fish showed apparent colour enhancement ($p<0.05$) when compared with the fish feed-fed fish, as shown in Fig. 3 and Table 5.

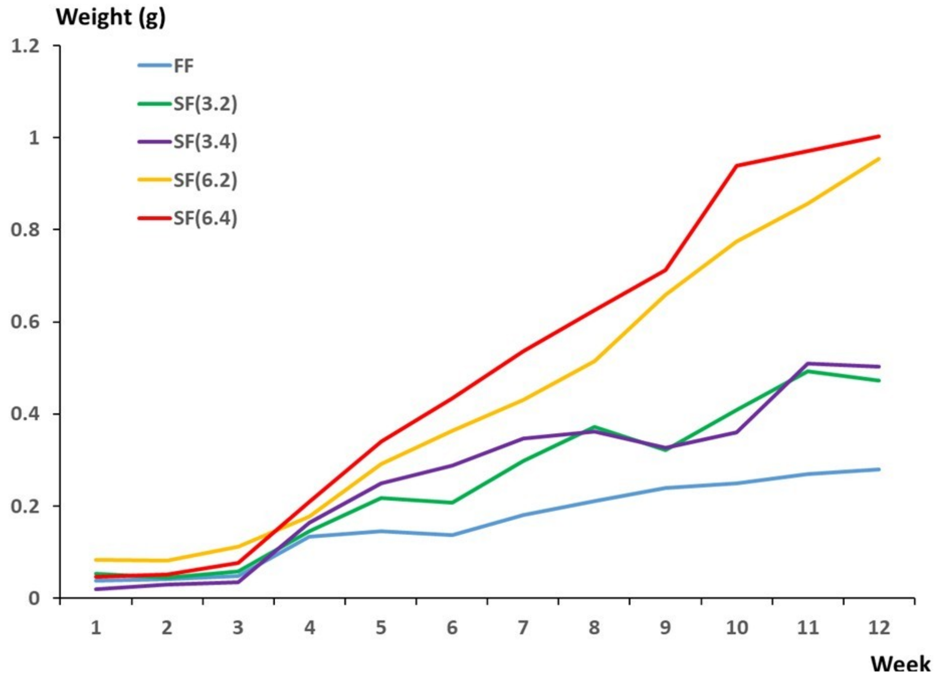

Figure 1. Growth curves of Guppy (*Poecilia reticulata*) fry treatments at varying feeding rates (%) and feeding frequencies during the experimental period. FF- Fish Feed (control), SF- shrimp feed, BW –Body Weight. FF; Commercial fish feed, SF(3.2); SF fed by 3% of BW and 2 times daily, SF(3.4); SF fed by 3% of BW and 4times daily, SF(6.2); SF fed by 6% of BW and 2 times daily, SF(6.4); SF fed by 6% of BW and 4 times daily.

Table 3. Growth performance of *Poecilia reticulata* fry treatments at varying feeding rates (%) and feeding frequencies during the experimental period.

Parameter	FF	SF(3.2)	SF(3.4)	SF(6.2)	SF(6.4)	P value
Initial weight (g/fish)	0.04±0.00	0.04±0.00	0.04±0.00	0.04±0.00	0.04±0.00	0.74
Final weight (g/fish)	$0.28{\pm}0.01^{a}$	$0.47{\pm}0.04^{ab}$	$0.50{\pm}0.04^{b}$	$0.96{\pm}0.06^{c}$	$1.00{\pm}0.07^{c}$	0.00
WG (g)	$0.23{\pm}0.01^{a}$	$0.43{\pm}0.04^{ab}$	$0.46{\pm}0.04^{b}$	$0.91{\pm}0.06^{c}$	$0.96{\pm}0.07^{c}$	0.00
DWG (g/day)	$3.02{\pm}0.18^{a}$	$5.62{\pm}0.49^{ab}$	$6.02{\pm}0.52^{b}$	$11.83{\pm}0.71^{c}$	$12.46{\pm}0.89^{c}$	0.00
RWG	$536{\pm}59^{a}$	$1064{\pm}81^{ab}$	$1159{\pm}100^{b}$	$2130{\pm}223^{c}$	$2213{\pm}58^{c}$	0.00
SGR	$2.77{\pm}0.12^{a}$	$3.41{\pm}0.07^{ab}$	$3.49{\pm}0.08^{b}$	$4.03{\pm}0.12^{c}$	$4.08{\pm}0.03^{c}$	0.00
Survival (%)	80±3	76±1	82±1	72±10	79±14	0.89

Notes: Mean±SE in each row, superscripted with lowercase letters, are significantly different ($p<0.05$); WG= Weight Gain; RWG= Relative Weight Gain; SGR= Specific Growth Rate. FF; Commercial fish feed, SF(3.2); SF fed by 3% of BW and 2 times daily, SF(3.4); SF fed by 3% of BW and 4 times daily, SF(6.2); SF fed by 6% of BW and 2 times daily, SF(6.4); SF fed by 6% of BW and 4 times daily.

Table 4. Grading results of *Poecilia reticulata* fry fed with fish feed (FF) and different shrimp feed (SF) percentages by BW with different feeding frequencies during the experimental period.

Parameter	FF	SF(3.2)	SF(3.4)	SF(6.2)	SF(6.4)
Fatty Liver	0	2	3	3	3
Steatohepatitis	0	2	3	3	3

FF; Commercial fish feed, SF(3.2); SF fed by 3% of BW and 2 times daily, SF(3.4); SF fed by 3% of BW and 4 times daily, SF(6.2); SF fed by 6% of BW and 2 times daily, SF(6.4); SF fed by 6% of BW and 4 times daily

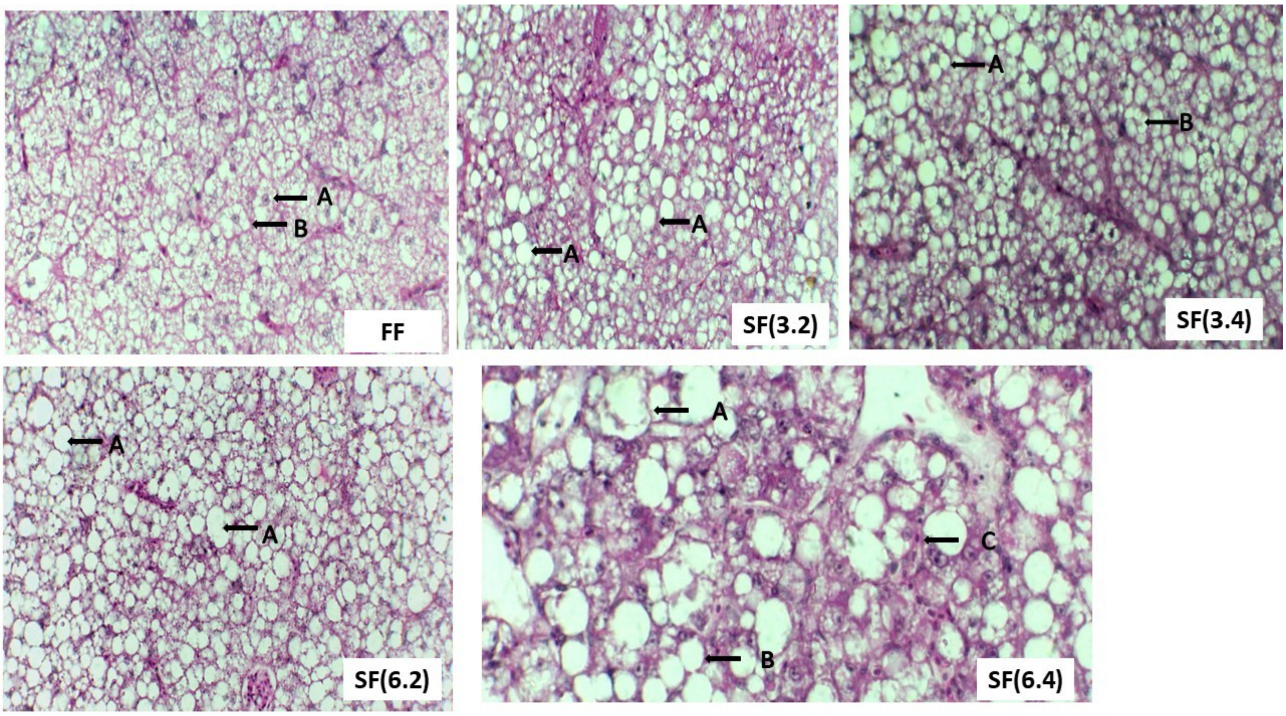

Figure 2. Representative images of the histology of hepatocytes of *P. reticulata* fry fed by different research diets as seen under the light microscope at 10×4 magnification (Euromex Microscopes, Arnhem, Netherlands). * FF) Central and round nucleus (A), Normal hepatic tissue (B), SF(3.2)) Fat globules (A), SF(3.4)) Fat globules(A), Degenerated nucleus (B), SF(6.2)) Fat globules (A) SF(6.4)) Degenerated Liver cells(A), Fat globules(B), Decentralized nucleus (C). FF; Commercial fish feed, SF(3.2); SF fed by 3% of BW and 2 times daily, SF(3.4); SF fed by 3% of BW and 4 times daily, SF(6.2); SF fed by 6% of BW and 2 times daily, SF(6.4); SF fed by 6% of BW and 4 times daily.

Table 5. MATLAB values (Greyscale) related to the colour intensities of *Poecilia reticulata* fed with fish feed (FF) and different shrimp feed (SF) percentages by BW with different feeding frequencies during the experimental period.

Parameter	FF	SF(3.2)	SF(3.4)	SF(6.2)	SF(6.4)	P value
MATLAB value	91.4±4.7^{a}	69.6±1.7^{b}	71.0±3.4^{b}	63.9±2.1^{b}	64.3±0.8^{b}	0.001

Notes: Mean±SE in each row, superscripted with different lowercase letters, are significantly different ($p<0.05$) FF; Commercial fish feed, SF(3.2); SF fed by 3% of BW and 2 times daily, SF(3.4); SF fed by 3% of BW and 4 times daily, SF(6.2); SF fed by 6% of BW and 2 times daily, SF(6.4); SF fed by 6% of BW and 4 times daily.

Table 6. Stress tolerance of *Poecilia reticulata* fed with fish feed (FF) and different shrimp feed (SF) percentages by BW with different feeding frequencies during the experimental period.

Parameter	FM	SF(3.2)	SF(3.4)	SF(6.2)	SF(6.4)	P value
Stress Tolerance	279.0±7.8	260.0±20.1	279.0±2.6	266.7±3.3	261.3±11.3	0.61

Notes: FF; Commercial fish feed, SF(3.2); SF fed by 3% of BW and 2 times daily, SF(3.4); SF fed by 3% of BW and 4times daily, SF(6.2); SF fed by 6% of BW and 2 times daily, SF(6.4); SF fed by 6% of BW and 4 times daily.

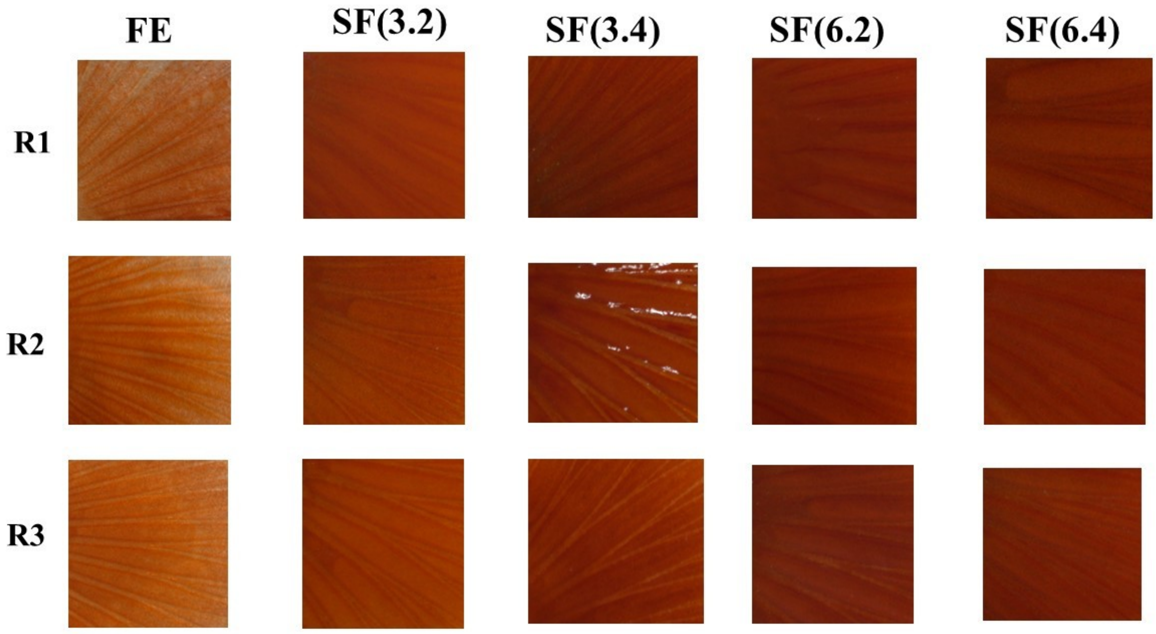

Figure 3. Represented digital photographs of cropped caudal fins of *P. reticulata* at the end of the experiment taken by Nikon D-7500 camera and YONGNUO YN 60 mm macro lens (Shutter speed: 1/40, Aperture: 8, and ISO: 320). Notes: FF; Commercial fish feed, SF(3.2); SF fed by 3% of BW and 2 times daily, SF(3.4); SF fed by 3% of BW and 4times daily, SF(6.2); SF fed by 6% of BW and 2 times daily, SF(6.4); SF fed by 6% of BW and 4 times daily.
R1, R2, and R3; the replicates of the relevant treatments

Stress tolerance

Results indicated that the type of feed (Tropical fish feed or commercial shrimp feed) did not affect for the stress tolerance in the researched fish. Moreover, feeding rate and feeding frequency of the fish fed the commercial shrimp feed did not affect stress tolerance (Table 6). Stress tolerance of *Poecilia reticulata* fed with fish feed (FF) and different shrimp feed (SF) percentages by BW with different feeding frequencies during the experimental period.

Discussion

Feeding is generally crucial in commercial aquaculture, especially in the ornamental fish industry, because growth, pigmentation, and immunity can be enhanced through optimal feeding. Therefore, alternative economical fish feeds such as trout, salmon, and shrimp feeds have been applied for the ornamental fish (Tamaru & Ako 1999, Karadal *et al*. 2018, Kumaratunga & Radampola 2019) because the ornamental fish feeds are 10-60 times more expensive than general aquafeeds, and the prices of the species-specific ornamental fish feeds vary dramatically (Tamaru & Ako 1999).

However, there are several complaints associated with feeding ornamental fish, especially guppies, with shrimp feeds, which have resulted in issues with liver functions such as fatty liver (Personnel Communication).

Pigmentation, maximum lifespan, body shape, and optimal liver function are the most important parameters expected in commercial ornamental fish farming, in addition to growth, which is a primary parameter in aquaculture. In contrast, maximum growth is expected to promote health during a short growth cycle in commercial shrimp farming, and several growth promoters are incorporated into the shrimp feeds (Kotiya *et al*. 2011). Thus, significantly higher growth performances of ornamental fish fed with shrimp feed are attributed to dedicated growth promoters included in commercial shrimp feeds.

Moreover, the results further confirmed that the feeding rate positively affected the growth performance of fish – that is, when guppies were fed 6% of shrimp feed by body mass, they achieved higher growth. Fish growth depends on several factors; among these, feeding rate is a crucial factor during early life stages (Goddard 1996). When the feeding rate increases, feed intake increases. The ingested nutrients are used to maintain the body, and the remaining portion of the nutrients could be used for growth.

While the feeding rate was maintained at 3% of the body weight, enhanced growth was observed in the SF(3.4) group compared to the fish fed commercial fish feed group. There was no significant difference between the FF and SF(3.2) groups. The feeding frequency was changed from 2 to 4; feed intake and the ingested nutrient amount increased. However, fish were fed at a rate of 6%; the growth was independent of feeding frequency. It is suggested that fish avoid feeding once they reach the maximum satiation level.

Shrimp by-products are included in shrimp feed, perhaps up to 30%, and shrimp waste is enriched with carotenoids (Meyers 1986, Ambati *et al*. 2014). Previous research confirmed that shrimp meal can entirely replace fishmeal in some fish diets (Cavalheiro *et al*. 2007, Jamabo & Dasimeokuma 2020). Further, it has been identified that including shrimp meal effectively enhances the growth (Cruz-Suarez *et al*. 1993).

For example, a shrimp paste-included diet has improved the growth performance of *Channa maculata*, enhancing the feed intake (Fang *et al*. 2019), and Putri *et al*. (2023) have shown that the incorporation of shrimp shell meal and fishmeal in the *Lates calcarifer* diet resulted in the highest growth rate when compared to the growth performance of the solely fishmeal-included diet.

Shrimp head meal/shrimp waste is a rich source of nutrients (i.e., higher crude protein level, balanced amino acid profile, richness in w-3 fatty acids and minerals) (Armenta & Guerrero-Legarreta 2009, Ramyadevi *et al*. 2012). Shrimp waste/paste could act as a feed attractant due to its availability of long-chain n-3 polyunsaturated fatty acids, free amino acids, nucleotides, amines, and nucleosides (Montano *et al*. 2001) and, further, it has a powerful aroma (Fang *et al*. 2019). The inclusion of marine fish oil acts as an attractant and enhances the feed intake, resulting in higher growth (Royes & Muries 2004).

The above chemicals are sensitive to the fish's chemosensory systems, which help them digest the feed (Suresh *et al*. 2011). Therefore, studies have shown that marine animal additives, such as shrimp paste/waste, act as attractants, and there is a potential to improve the palatability of fish by arousing appetitive behaviour and increasing feed consumption (Derby *et al*. 2016). In addition, shrimp paste regulates the enzyme secretion in fish, thereby improving digestion (Fang *et al*. 2019).

All the shrimp feed-fed fish groups showed higher pigmentation, and feeding rate and frequency did not affect the colour intensity. Shrimp feeds are enriched with shrimp meal/waste, as mentioned above, and shrimp waste is a rich source of carotenoids (Babu *et al*. 2008). Carotenoids are responsible for the skin pigmentation in aquatic species such as fish (Matsuno 2001). Fish cannot synthesize carotenoids; therefore, pigmentation depends on dietary pigment deposition (Goodwin 1984).

Researchers have shown that feed additives can improve the colour intensity of ornamental fish (Uribe *et al*. 2018, Perera *et al*. 2024a, Perera *et al*. 2024b, Sathyaruban *et al*. 2024). Astaxanthin can be synthesized from shrimp waste, and it was found that the above astaxanthin-included diet enhanced the pigmentation of goldfish within a shorter period (Weeratunge & Perera, 2016). The supplementation with shrimp shell meal in the diet of large yellow croaker (*Larimichthys croceus*) has significantly increased skin pigmentation and total carotenoid content (Yi *et al*. 2015).

It has been identified that fatty liver disease is the most common metabolic disorder and the most frequent cause of mortality in ornamental fish (Penrith *et al*. 1994). In contrast to the better growth performance and pigmentation obtained by the shrimp feed-fed fish, shrimp feeding resulted in fatty liver and steatohepatitis in the same fish group (Fig. 2 and Table 4). The damage intensity worsened when the feeding frequency was increased.

Previous work confirmed that the two ornamental cichlids (*Pseudotropheus socolofi* and *Haplochromis ahli*) showed excess lipid deposition and necrosis of the liver when these fish were fed with trout commercial feed with high lipid content (17%) (Royes & Murie 2004). It has been identified by the previous experiments that the common factor for fatty liver among the species such as juvenile European seabass, African cod, channel catfish, flag cichlid, and captive African catfish was the continuous feeding of a high-energy, high lipid (e.g., .10% lipid), formulated feeds (Royes & Muries 2004). However, the proximate composition indicated that the lipid content and energy level of the used shrimp feed were low and not significantly different from those of the control feed (Table 1).

Therefore, the liver alterations may not be due to the higher lipid content or energy percentages, as explored by the above findings. Pelleted feeds are formulated to support higher growth at a lower cost for targeted species (Royes & Muries 2004). In this regard, commercial shrimp feeds have been formulated to achieve maximum weight gain in a shorter period, as described above. Thus, shrimp feed could be an alternative feed for ornamental fish such as guppies to promote growth. Moreover, it is best suited to enhance the pigmentation of the fish.

On the contrary, poor liver conditions have resulted due to the higher feeding rate (6%) and higher feeding frequency (4). The above practices induce fish to increase by providing feed attractants (Kurnia *et al*., 2025). Researchers have identified that fatty liver in fish is associated with higher feeding frequency, and excessive feed intake (Wu *et al*. 2021). Simultaneously, there is potential to store excess dietary lipids as lipid droplets in liver hepatocytes, increasing the risk of fatty liver (Crowe *et al*. 2021). The above findings are comparable to the output of this research. Furthermore, Paperna *et al*. (1977) proved that the liver cells recovered to normal after a balanced diet was resumed.

Thus, the sustainable option is to use the specific feeds for the ornamental fish. However, considering the advantages of the commercial shrimp feeds such as cost-effectiveness, higher growth and colour performance, shrimp feed can be recommended as an alternative feed with optimum feeding rates and frequencies.

CONCLUSION

The results of this experiment confirmed that the use of commercial shrimp feed as a feed for *Poecilia reticulata* fry enhances growth performance and pigmentation significantly, while its effect on stress tolerance is neutral. However, more importantly, the application of commercial shrimp feed in *P. reticulata* fry adversely affects hepatic cells and liver health; thus, prolonged use of shrimp feed at higher rates and frequencies is not recommended. Therefore, when species-specific feeds are unavailable or expensive, it is sustainable to use commercial shrimp feed under restricted feed strategies, such as controlling feed frequency and rate, to ensure fish welfare.

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