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Growth Performance of Three-Spotted Tilapia *(Oreochromis andersonaii)* Fed Diets Containing Red-Claw Crayfish Meal as a Partial Replacement for Fishmeal

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Abstract

The rising cost and limited availability of fishmeal are key constraints to sustainable aquaculture feed formulation. This has necessitated research into alternative protein sources that are locally available, cost effective, and nutritionally adequate. This study evaluated red-claw crayfish meal (CFM) as an alternative protein source for three-spotted tilapia (*Oreochromis andersonaii*) fingerlings. A total of 180 sex-reversed fingerlings (1.6 ± 0.5 g) were randomly assigned to three dietary treatments: T1 (CFM at 40% inclusion level), T2 (FM at 40% inclusion level), and T3 (commercial feed, control), with other ingredients including maize meal, cassava, and vitamin premix. The treatments were arranged in a completely randomized design with three replicates and 20 fingerlings per treatment. Fish were fed at 5% body weight twice daily for six weeks. Water quality parameters remained within acceptable ranges (dissolved oxygen: 3.5–5.0 mg/L; pH: 6.8–7.4; ammonia: 0.09–0.85 mg/L). Results showed that fish fed the CFM-based diet (T1) exhibited comparable growth performance to those fed the FM-based diet (T2) and the commercial control diet (T3), with no significant differences ($p > 0.05$) observed in final weight, feed intake, feed conversion ratio, or standard length among treatments. The findings suggest that red-claw crayfish meal can be included at 40% in the diet of three-spotted tilapia fingerlings without compromising growth performance, offering a promising sustainable alternative to fishmeal in aqua feed formulations.

Keywords: Aqua feed sustainability, Crayfish meal, Fishmeal replacement, growth performance, *Oreochromis andersonaii*

Introduction

Aquaculture continues to expand globally as a critical source of animal protein for human consumption, with tilapia production playing a significant role in meeting food security demands, particularly in developing countries (FAO, 2022). However, the sustainability of aquaculture production is threatened by the industry's heavy reliance on fishmeal as the primary protein source in aqua feeds (Tacon & Metian, 2015). Fishmeal production depends on wild-caught forage fish stocks, which are increasingly overexploited, leading to escalating costs and supply volatility (Shepherd & Jackson, 2013).

The search for sustainable, cost-effective alternative protein sources has intensified, with particular interest in utilizing locally available biological resources that would otherwise be considered waste (Gatlin et al., 2007). Invasive species management presents a unique opportunity for resource valorization, as converting invasive biomass into aqua feed ingredients could simultaneously reduce reliance on fishmeal and offset the costs of invasive species control (Tonges et al., 2021).

The Australian red-claw crayfish (*Cherax quadricarinatus*) has become a significant invasive species in Zambia's freshwater ecosystems, particularly in the Kafue River and Lake Kariba

(Nakayama et al., 2023). The species has established robust populations with multiple age classes, causing substantial ecological damage through predation on native fish eggs and fry, competition for resources, and damage to fishing gear (Madzivanzira et al., 2022). A 2023 survey of 342 fishers reported that over 90% of respondents confirmed crayfish damage to fish catches, with approximately 50% reporting damage to fishing gear (Phiri et al., 2023). Despite this, 59% of fishers still discard captured crayfish, viewing them as a nuisance rather than a valuable resource (Phiri et al., 2023).

Previous studies have investigated the potential of crayfish meal as a protein source in aqua feeds for various fish species. Capoccioni et al. (2025) demonstrated that including 12% red swamp crayfish meal in seabream diets significantly increased omega-3 fatty acid content and reduced lipid peroxidation markers while maintaining growth performance comparable to conventional diets. Digestibility trials in rainbow trout and European seabass confirmed that red swamp crayfish meal has high apparent digestibility coefficients for dry matter, crude protein, and energy (Capoccioni et al., 2024). However, studies on tilapia species have shown variable results, with some research indicating that crayfish meal should be limited to 25-50% replacement of fishmeal in *O. niloticus* diets to maintain optimal growth, feed utilization, and fish health (Abd El Hady et al., 2019).

The reduced growth observed with crayfish meal-based diets in some studies may reflect poor protein utilization due to unfavorable amino acid profiles and protein quality (Carlos et al., 1988), as well as higher dietary ash content and lower digestibility (Keremah, 2008). Low digestibility is associated with chitin, a structural polysaccharide in crustaceans and mollusks, which can physically hinder digestive enzymes from accessing lipids and proteins, thereby limiting nutrient utilization (Karasov, 1990, as cited by Jean et al., 2012).

The three-spotted tilapia (*Oreochromis andersonaii*) is a native African tilapia species of significant economic importance in Zambia and the broader Zambezi River basin (Msiska, 2001). Unlike the widely studied Nile tilapia (*O. niloticus*), the response of *O. andersonaii* to alternative protein sources has received limited research attention. This study, therefore, aimed to evaluate the growth performance of three-spotted tilapia fingerlings fed diets containing red-claw crayfish meal at 40% inclusion level as a partial replacement for fishmeal, compared to fishmeal-based and commercial control diets.

Materials and Methods

Ethical approval

This research's implementation has obtained a permit stipulated by Mulungushi University, Directorate of Research and Innovation with Certificate number MU/DR/REC/2026/162

Study Site and Duration

The feeding trial was conducted at Ozone mate gardens fish farm in Serenje district, central province of Zambia. The experiment lasted 43 days, from 10th March to 21st April 2026.

Experimental Fish and Rearing Conditions

A total of 180 sex-reversed three-spotted tilapia (*Oreochromis andersonaii*) fingerlings with an initial average weight of 1.6 ± 0.5 g were obtained from Chalata government fish hatchery and acclimatized to laboratory conditions for seven days prior to the experiment. Fish were randomly distributed into nine rectangular fiberglass tanks (60 L capacity) at a stocking density of 20 fish per tank. The tanks were supplied with dechlorinated municipal water and continuously aerated using air stones connected to an air pump. Water quality parameters were monitored weekly and maintained within acceptable ranges: dissolved oxygen (3.5–5.0 mg/L), pH (6.8–7.4), and total ammonia nitrogen (0.09–0.85 mg/L). Temperature was maintained at 27 ± 1°C throughout the experimental period.

Experimental Diets and Formulation

Three isonitrogenous and isolipidic experimental diets were formulated and prepared for the study:

- T1 (Crayfish Meal Diet): Contains red-claw crayfish meal at 40% inclusion level, supplemented with maize meal, cassava, and vitamin premix.
- T2 (Fishmeal Diet): Contains fishmeal at 40% inclusion level, supplemented with maize meal, cassava, and vitamin premix.
- T3 (Control Diet): Commercial fish feed currently used in the Zambian aquaculture sector.
- The red-claw crayfish used for meal preparation were sourced from the Kafue River through local fisher cooperatives. Crayfish were processed following established protocols: washed, frozen at -20°C, ground, oven-dried at 60°C for 48 hours, and finely milled to produce a homogeneous meal. Proximate analysis of the crayfish meal revealed a crude protein content of 40.47% ± 0.52% (Chipanda et al., unpublished data).

Nutritional Composition and Nutritional Value of Crayfish meal

In diets for animals, it could be noticed in table 1 that the protein in crayfish meal has a high biological value. It is rich in essential amino acids (EAA) particularly lysine, and sulphur amino acids while, the high values of non-essential amino acids (NEAA) were found in glutamic acid and aspartic acid. Therefore, the presence of crayfish meal in a complete diet will supplement any deficiencies of the amino acids in vegetable proteins. Also, the nutritional quality was confirmed by the high of total amino acids (TAA), total essential amino acids (TEAA), amino acid index (AAI) and biological value

(B.V. %). Where, TAA was 73.90 g/16gN, TEAA was 34.62 g/16gN, TEAAI was 67.66 g/16gN and B.V. was 62.02 %. Similar results were found by **Ghaly (1995), Hussein (1997) and El-Sherif (2001).**

Table 1 Amino acid composition and nutritional value of crayfish meal (Shaban A.El-Sherif et al., 2021)

Amino acids	g/16g N	Amino acids	g/16g N
Aspartic acid (Asp)	8.06	Tyrosine (Tyr)*	1.55
Threonine (Thr)*	3.21	Phenylalanine (Phe)*	3.12
Serine (Ser)	3.10	Histidine (His)*	2.03
Glutamic acid (Glu)	11.22	Lysine (Lys)*	7.21
Glycine (Gly)	4.18	NH4	Nd
Alanine (Ala)	5.20	Arginine (Arg)	4.66
Valine (Val)*	4.15	Proline (Pro)	2.86
Methionine (Met)*	2.52	Cystine (Cys)*	0.86
Isoleucine (Ile)*	3.02	Tryptophan (Try)*	0.86
Leucine (Leu)*	6.95		Nd
Total amino acid	73.90		
Total essential amino acids	34.62		
Total essential amino acids index	67.66		
Biological value (%)	62.02		

Essential amino acids, nd: not detected

Table 2: Composition and nutritive value of diets in percentage (Evans, 2008)

Diet	Crayfish Meal	Fish Meal	Maize Bran	Cassava Meal
Dry matter	92.1	87.0	89.0	87.1
Crude protein	58.2	61.0	9.8	7.4
Oil (either extract)	21.0	3.5	4.3	3.8
Carbohydrates	Trace	Trace	90.52	89.4
(N2 free extractives)	1.2	1.5	72.5	65.8
Crude fiber	14.2		1.5	1.0
Ash	17.30	21.0	0.9	0.6
True protein	52.8	57.0	9.4	10.3
Digestible Nutrients				
Digestible oil	49.4	55.0	9.4	10.3
Digestible Carbohydrates	46.4	3.3	2.0	4.6
Mineral Composition				
Cao	87.1	79.1	0.13	0.29
P2OS	2.4	1.2	70.4	80.6
K20	12.8	15.2	0.5	0.1
Mg	18.1	10.0	Trace	Trace

Feeding Trial and Management

Fish were fed at 5% of their body weight per day, divided into two equal meals (morning and afternoon) for six weeks. Feed quantities were adjusted weekly based on weight measurements. Feed intake was recorded daily by weighing uneaten feed after 30 minutes of feeding. Fish were weighed individually every two weeks using a digital balance (Sartorius, ±0.01 g accuracy), and standard length was measured using a measuring board. Mortalities were recorded daily.

Growth Performance Parameters

The following growth performance parameters were calculated:

Weight gain (WG) = Final weight - Initial weight

Feed conversion ratio (FCR) = Feed intake (g) / Weight gain (g)
Specific growth rate (SGR) = [(Ln final weight - Ln initial weight) / Number of days] × 100
Condition factor (K) = (Body weight / Standard length^3) × 100
Survival rate (%) = (Final number of fish / Initial number of fish) × 100

Statistical Analysis

Data on growth performance and feed utilization were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). The data were subjected to one-way analysis of variance (ANOVA) to test for significant differences among dietary treatments. When significant differences were detected, means were compared using Tukey's honestly significant difference (HSD) post-hoc test at a significance level of $p < 0.05$. Data were expressed as mean ± standard deviation (SD). Prior to analysis, data were checked for normality using the Shapiro-Wilk test and homogeneity of variances using Levene's test.

Results

Water Quality Parameters

Water quality parameters remained within acceptable ranges for tilapia culture throughout the experimental period. Mean values were: temperature 27.0 ± 1.0°C, dissolved oxygen 4.2 ± 0.7 mg/L, pH 7.1 ± 0.3, and total ammonia nitrogen 0.47 ± 0.28 mg/L. No significant differences were observed among treatments for any water quality parameter ($p > 0.05$).

Growth Performance and Feed Utilization

The growth performance and feed utilization parameters of three-spotted tilapia fingerlings fed experimental diets for six weeks are presented in Table 3. The initial weight of fish across treatments was not significantly different ($p > 0.05$), confirming successful randomization.

Table 3: Growth Performance of Three-Spotted Tilapia Fed Experimental Diets

Parameter	T1 (Crayfish Meal)	T2 (Fishmeal)	T3 (Commercial Control)
Initial Weight (g)	1.60 ± 0.03	1.60 ± 0.02	1.60 ± 0.03
Final Weight (g)	3.64 ± 0.03	3.68 ± 0.07	3.76 ± 0.23
Weight Gain (g)	2.04 ± 0.04	2.08 ± 0.07	2.16 ± 0.22
Feed Intake (g)	4.75 ± 0.56	4.29 ± 0.32	4.73 ± 0.44
FCR	1.30 ± 0.14	1.25 ± 0.21	1.26 ± 0.16
Standard Length (mm)	39.61 ± 2.61	39.73 ± 1.75	38.36 ± 3.10
Survival Rate (%)	100	100	100

Values are presented as mean ± SD (n=3 replicates per treatment). Means in the same row are not significantly different (p > 0.05).

Final Weight (g)

Fish fed the control commercial diet (T3) showed the highest final weight (3.76 ± 0.23 g), followed by T2 (fishmeal diet; 3.68 ± 0.07 g) and T1 (crayfish meal diet; 3.64 ± 0.03 g). However, one-way ANOVA revealed no significant differences in final weight among the three dietary treatments ($F (2, 6) = 0.481$, $p = 0.640$). All treatments supported comparable growth over the six-week feeding period.

Feed Intake (g)

Total feed intake was highest for T1 (crayfish meal diet; 4.75 ± 0.56 g), followed by T3 (commercial control; 4.73 ± 0.44 g) and T2 (fishmeal diet; 4.29 ± 0.32 g). The differences in feed intake among treatments were not statistically significant ($F (2, 6) = 1.218$, $p = 0.359$).

Feed Conversion Ratio (FCR)

The FCR values ranged from 1.25 ± 0.21 (T2, fishmeal diet) to 1.30 ± 0.14 (T1, crayfish meal diet), with T3 (commercial control) recording a value of 1.26 ± 0.16. One-way ANOVA indicated no significant differences in FCR among the three treatments ($F (2, 6) = 0.097$, $p = 0.909$). All diets exhibited acceptable feed conversion efficiency, with FCR values below 1.5, which is considered favorable for tilapia fingerling production.

Standard Length (mm)

Final standard length was comparable across treatments, with values of 39.61 ± 2.61 mm (T1), 39.73 ± 1.75 mm (T2), and 38.36 ± 3.10 mm (T3). The differences were not statistically significant ($F (2, 6) = 0.259$, $p = 0.779$).

Survival Rate

Survival rate was 100% across all treatments throughout the experimental period, indicating that none of the diets had adverse effects on fish health or survival.

Discussion

This study evaluated the growth performance of three-spotted tilapia (*Oreochromis andersonaii*) fingerlings fed diets containing red-claw crayfish meal at 40% inclusion level as a partial replacement for fishmeal. The results demonstrated that the crayfish meal-based diet (T1) supported growth performance comparable to both the fishmeal-based diet (T2) and the commercial control diet (T3), with no significant differences observed in final weight, weight gain, feed intake, FCR, or standard length among treatments.

These findings contrast with some previous studies that reported reduced growth when crayfish meal was included at higher levels in tilapia diets. Abd El Hady et al. (2019) reported that crayfish meal should be limited to 25-50% replacement of fishmeal in *O. niloticus* diets to maintain optimal growth. The present study's 40% inclusion level falls within this recommended range, and the comparable growth performance observed supports the conclusion that this inclusion level is appropriate for *O. andersonaii*. The results suggest that the native African tilapia species may respond similarly to the more extensively studied Nile tilapia regarding alternative protein utilization.

The feed conversion ratios observed in this study (1.25-1.30) were within the acceptable range for tilapia fingerling production. FCR values below 1.5 are considered favorable, indicating efficient feed utilization (El-Sayed, 2006). The absence of significant differences in FCR among treatments suggests that fish were able to utilize the crayfish meal-based diet as efficiently as the fishmeal-based and commercial diets. This finding is consistent with the results of Capoccioni et al. (2024), who reported high apparent digestibility coefficients for red swamp crayfish meal in rainbow trout and European seabass.

However, the present results differ from earlier studies that documented reduced digestibility associated with crayfish meal inclusion. Keremah (2008) reported lower digestibility in diets containing crayfish meal, which was attributed to the presence of chitin, a structural polysaccharide in crustacean exoskeletons. Similarly, Carlos et al. (1988) identified poor protein utilization due to unfavorable amino acid profiles as a limiting factor. The comparable FCR observed in the present study may be explained by several factors. First, the processing of crayfish meal at 60°C for 48 hours may have partially hydrolyzed chitin, improving nutrient accessibility and digestibility (Hromis et al., 2024). Second, the incorporation of other ingredients such as maize meal and cassava in the formulated diets may have provided complementary amino acid profiles, mitigating potential deficiencies in essential amino acids (Tacon & Metian, 2015).

The inclusion of chitin in crustacean meal has been reported to have both positive and negative effects on fish performance. While chitin can hinder digestive enzyme activity (Karasov, 1990, as cited by Jean et al., 2012), it may also exert prebiotic effects by modulating intestinal microbiota composition and enhancing immune function (Zarantoniello et al., 2023). The 100% survival rate observed across all treatments in the present study indicates that the crayfish meal diet did not adversely affect fish health or immunocompetence.

The water quality parameters recorded throughout the study remained within acceptable ranges for tilapia culture. Dissolved oxygen levels (3.5-5.0 mg/L), pH (6.8-7.4), and ammonia concentrations (0.09-0.85 mg/L) were consistent with values reported by El-Sayed (2006) as optimal for tilapia growth and health. The uniform water quality across treatments supports the conclusion that observed growth performance differences, or lack thereof, were primarily attributable to dietary treatments rather than environmental factors.

Lima Ren (2026) examined and indicated that even low-level inclusion (around 2%) of crayfish processing by-products and protein hydrolysates helps mitigate the negative growth and metabolic impacts of low-fishmeal diets by improving intestinal microbiota and feed palatability. In his study, Matteo (2023) demonstrated that specific crustacean meal inclusions support healthy distal intestine histomorpholory in aquaculture species. And in his study, Kabati.C (2025) evaluated that while black soldier fly larvae meal could completely replace fishmeal, red-claw crayfish meal and blood meal performed best when used as partial replacements due to growth metrics.

The comparable growth performance of fish fed the crayfish meal diet is of particular significance in the Zambian context. The red-claw crayfish has become a major invasive species in Zambian water bodies, causing substantial ecological damage and economic losses to local fishers (Madzivanzira et al., 2022, Phiri et al., 2023). The present study demonstrates that this invasive biomass can be valorized as a valuable feed ingredient, offering a dual benefit: (1) reducing reliance on imported fishmeal, and (2) creating economic incentives for crayfish population control through commercial utilization (Tonges et al., 2021).

Economic Viability

Traditional fishmeal is expensive and subject to market price spikes. Local or byproduct crayfish meal provides a cheaper, locally available protein source that cuts overall feed formulation expenses. Abd EL-Aty (2006) reported that crayfish meal can be successfully used up to 33% replacement of fishmeal of the Nile tilapia diets to reduce feeding costs. Without sacrificing economic returns, research shows that substituting 25% to 50% of fish meal protein with crayfish meal achieves a balanced feed conversion ratio (FCR), while total (100%) replacement often decreases weight gain and lowers feed efficiency making it less economically viable unless supplemented with specific amino acids (Add EL-Aty, 2006).

The economic implications of replacing fishmeal with locally available crayfish meal are substantial. Zambia currently imports all fishmeal used in commercial aqua feeds, contributing to high production costs and vulnerability to international market fluctuations (Mukuka et al., 2022). The availability of a locally sourced alternative protein source at comparable performance levels could significantly reduce aqua feed costs and improve the economic viability of tilapia farming operations in Zambia. Furthermore, the utilization of crayfish meal may stimulate community-based crayfish harvesting programs, generating additional income for fishing communities while contributing to invasive species management efforts (Phiri et al., 2023).

The findings of this study align with the broader circular economy concept, where waste from one system becomes a resource for another. The valorization of invasive crayfish biomass through aqua feed production represents a practical application of this concept in the Zambian context. Converting an ecological liability into a productive resource addresses multiple Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), SDG 14 (Life below water), and SDG 15 (Life on Land).

Conclusion

Red-claw crayfish meal can be included at 40% in the diet of three-spotted tilapia fingerlings without compromising growth performance, feed utilization, or survival. No significant differences were observed in final weight, feed intake, FCR, or standard length between fish fed crayfish meal-based diets and those fed fishmeal-based or commercial control diets.

Crayfish is a threat to biodiversity loss. Their impacts include destruction of aquatic plants causing habitat change, predation on fish and amphibian eggs and disturbance of fish breeding habitats (Foster et al., 2012). Therefore, this study will help contribute in sustainable utilization of the Invasive Cray fish as a natural resource, using it as a feed ingredient in fish diet, thereby maintaining the population of crayfish in the water bodies, which will also help reduce biodiversity loss. The cost of feed is significantly expensive to aquaculture producers, so developing more cost-effective solutions is also important. The need to develop sustainable feed products in its self creates an economic opportunity. Since it has been established that crayfish is in abundance and that it might be a cheaper source of animal protein as an ingredient in fish feed, therefore this study will help contribute lowering the cost of production in fish feed formulation thereby boosting the growth of aquaculture in Zambia as well as reduction in over exploitation of fish to be used as the primary source of fish feed, as over exploitation is also one of the threats to biodiversity loss.

The crayfish meal-based diet supported acceptable feed conversion ratios (1.30), indicating efficient nutrient utilization by three-spotted tilapia.

The 40% inclusion level of crayfish meal falls within the recommended range established for *O. niloticus* (25-50%), suggesting that *O. andersonaii* responds similarly to alternative protein sources. The use of crayfish meal in tilapia diets represents a promising strategy for reducing reliance on expensive imported fishmeal while creating economic value from invasive species biomass.

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