



Research Article

Mealworm (*Tenebrio molitor*) Meal Supplementation in Commercial Diets Enhances Growth Performance and Nutritional Profile of Hybrid Catfish

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ABSTRACT

Fish feed accounts for over 60% of aquaculture production costs, with fishmeal becoming increasingly scarce and expensive. This study evaluated the effects of coating commercial diets with mealworm (*Tenebrio molitor*) meal produced from larvae reared on fruit-waste substrates on the growth and carcass composition of hybrid catfish. An eight-week feeding trial was conducted and seven diets were tested: a control commercial Blue Crown® feed and six experimental diets coated with 2% and 4% mealworm meal per kg of the feed, obtained from larvae reared on wheat bran (WB), wheat bran with watermelon rinds (WB/WR), and wheat bran with pineapple and watermelon rinds (WB/PP/WR). Dietary proximate composition differed significantly, with crude protein ranging from 31.55±0.01 (D) to 38.22±0.02 (B2), fat from 9.15±0.13 (A1) to 13.23±0.54 (C2), ash from 7.36±0.02 (A2) to 8.70±0.10 (C1), moisture from 7.96±2.74 (A1) to 11.45±0.05 (B2), and carbohydrate from 45.00±0.12 (C1) to 50.72±0.02 (A1). The results of the growth performance revealed that the weight gain (33.44±0.44) and specific growth rate (1.27±0.06) were highest in fish fed diet containing 2% mealworm protein reared exclusively on wheat bran. The survival rates were high across the diets and the water quality parameters were within acceptable limits for trials on catfish. Carcass proximate and mineral composition revealed no significant differences among the treatments, and was within nutritionally acceptable ranges. Therefore, inclusion of mealworm meal at low levels improved growth performance without compromising carcass nutritional quality, which supports the use of insect protein from fruit-wastes as sustainable alternative to fishmeal in aquaculture feeds.

Keywords: Fruit wastes; Growth performance; Hybrid catfish; Mealworm meal; Nutrient composition

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INTRODUCTION

The global need for affordable and sustainable protein sources for aquafeed has increased due to the rapid growth of aquaculture worldwide (FAO, 2020). Due to its growing cost, erratic supply, and ecological effects on wild fish supplies, fishmeal the main

protein component of the majority of commercial diets faces significant constraints (Tacon and Metian, 2015; Hussain *et al.*, 2024). These challenges have prompted the need of finding alternative, ecologically friendly protein sources that can promote fish growth. Insects particularly the yellow mealworm has gained more interest as innovative protein sources

for aquaculture due to their balanced amino acid composition and high crude protein content (Van Huis, 2013). When compared to traditional livestock systems, insect production uses less resources and generates low emissions into the environment (Oonincx *et al.*, 2015).

Previous studies have highlighted the potentials of rearing mealworm on a variety of organic wastes such as fruit and plant debris, which can effectively bio-convert waste into high quality insect biomass (Govorushko, 2019; Harsanyi *et al.*, 2020; Rumbos *et al.*, 2021, Kotsou *et al.*, 2024; Musembi *et al.*, 2024). This offers the dual advantages of waste reduction and sustainable protein production, and it is consistent with the concepts of the circular economy which involves the recycling of wastes into forms that can be reused. Adding mealworm meal to aquafeeds has proven to be successful for a number of species. For instance, full-fat and defatted *T. molitor* meals have been demonstrated to support growth performance equivalent to fishmeal-based diets in rainbow trout and African catfish (*Clarias gariepinus*) (Fasakin *et al.*, 2003; Jeong *et al.*, 2020; Stone *et al.*, 2020). However, the nutritional value of mealworms can vary depending on the substrate used during rearing (Jankauskienė *et al.*, 2024), and limited studies have evaluated the performance of fish fed mealworm protein specifically derived from fruit-waste substrates.

Hybrid catfish (*Clarias gariepinus* × *Heterobranchus bidorsalis*) is one of the important aquaculture species, due to its fast growth rate and high market value (Solomon and Okomoda, 2012). However, despite their commercial importance, limited studies have been conducted on the use of mealworm protein produced from fruit-waste as a dietary supplement in aquafeed rather than a complete replacement for fishmeal. In other, to promote sustainable aquafeed development, it is crucial to comprehend how these protein sources affect growth and feed usage. Therefore, the purpose of this study is to assess the growth performance and carcass nutrient composition of hybrid catfish fed diets supplemented with mealworm meal produced from fruit-waste substrates.

MATERIALS AND METHODS

Collection and Processing of larvae

Mealworm larvae were reared following the procedure described by Rumbos *et al.* (2021) with slight modifications. Pineapple and watermelon rinds were washed, chopped and air dried before use. Three substrate treatments were prepared: wheat

bran only (WB; 100%), a mixture of wheat bran and watermelon rinds (WB/WR; 50 g wheat bran and 50 g watermelon rinds), and a mixture of wheat bran, pineapple peels, and watermelon rinds (WB/PP/WR; 50 g wheat bran, 25 g pineapple peels, and 25 g watermelon rinds). The larvae were harvested after a twelve (12) weeks trial and dipped in water at 100°C for 3 minutes. The larvae were oven dried at 60 °C for 24 hours, ground into fine particles using an electric blender (Siemianowska *et al.*, 2013) and analyzed for proximate composition.

Experimental diets

Seven (7) experimental diets were formulated following the procedures described by Sirbu *et al.* (2022) and Moreira *et al.* (2025) with some modifications. Six diets were prepared with the inclusion of mealworm (*Tenebrio molitor*) meal at two inclusion levels (2% and 4%), in addition to a control diet. Diet A1-Blue crown® supplemented with 2% mealworm meal reared exclusively on wheat bran (WB); Diet A2-Blue crown supplemented with 4% mealworm meal reared exclusively on wheat bran (WB); Diet B1-Blue crown supplemented with 2% mealworm meal reared on wheat bran and watermelon rinds (WB/WR, 50:50); Diet B2-Blue crown supplemented with 4% mealworm meal reared on wheat bran and watermelon rinds (WB/WR); Diet C1-Blue crown supplemented with 2% mealworm meal reared on wheat bran, pineapple, and watermelon rinds (WB/PP/WR, 50: 25:25); Diet C2-Blue crown supplemented with 4% mealworm meal reared on wheat bran, pineapple, and watermelon rinds (WB/PP/WR); Diet D (Control diet- Blue crown fish feed).

The standard commercial feed (Blue Crown) served as the control diet. For each diet, the required quantity of mealworm meal was weighed and mixed with the feed by continuous stirring. 20ml of water was gradually added to ensure homogeneity and proper mixing. The prepared diets were subsequently air-dried for 48hours to ensure proper drying. The dried feeds were then stored in airtight containers for further use. The proximate composition of the diets was analyzed according to the method of Association of Official Analytical Chemists (AOAC, 2019).

Collection and acclimation of experimental fish

Two hundred (200) hybrid catfish (*Heterobranchus bidorsalis* & *Clarias gariepinus*) juvenile (average initial weight of 17.05g- and length of 14.5cm) were purchased from a fish farm and transported in a 25L jerry can containing water to the laboratory. The fish were allowed to acclimatize to the laboratory condition for fourteen (14) days feeding on

commercial fish feed (Blue-crown) prior to the start of the experiment.

Experimental design

The feeding trial was carried out in a completely randomized design in 14 plastic containers (35 L); 7 treatments with 10 juveniles per replicate in each setup. Prior to the start of the experiment, the containers were cleaned, dried and filled with fresh tap water. Fish was fed 3% of body weight twice daily (9:00 am and 5:00 pm) for 8 weeks.

Growth performance of hybrid catfish fed diet supplemented with mealworm protein

The growth performance of hybrid catfish fed mealworm meal was determined bi-weekly. The weight of the fish in each container was recorded using a weighing scale and their total length was measured using a meter rule. Fish was removed from each aquaria using a seine, and returned following measurement. Weight gain (g), specific growth rate (%), Feed Conversion Ratio (FCR), Feed conversion efficiency (FCE) and Survival rate (%), was calculated using the following equations:

$$\text{Mean weight gain (g)} = \frac{\text{Final mean weight (Wf)} - \text{Initial mean weight (Wi)}}{t} \quad (1)$$

$$\text{Percentage weight gain} = \frac{\text{Final mean weight} - \text{initial mean weight}}{\text{initial mean weight}} \times 100 \quad (2)$$

$$\text{Specific growth rate (\%)} = \frac{\ln W_f - \ln W_i}{t} \times 100 \quad (3)$$

Where; Wf and Wi represent final and initial weight respectively
t represents time duration (days)

$$\text{Feed conversion ratio (\%)} = \frac{\text{Feed consumed}}{\text{weight gain}} \times 100 \quad (4)$$

$$\text{Feed conversion efficiency (\%)} = \frac{\text{Weight gain}}{\text{Feed intake}} \times 100 \quad (5)$$

$$\text{Survival rate (\%)} = \frac{\text{total number of fish stocked} - \text{total number of fish survived}}{\text{number of fish stocked}} \times 100 \quad (6)$$

Condition factor (k)

The condition factor “K” was determined for each sampled fish, following the procedures reported by Jimoh *et al.* (2019). The ratio of the length to the weight of the fish was determined as the function of the fish weight.

$$\text{Condition Factor (K)} = \frac{W \times 100}{L^3} \quad (6)$$

Where;

W=weight of fish in g

L= Length of fish in cm

Water quality parameters

Water quality parameters, including temperature, pH, dissolved oxygen, total dissolved solids, and

conductivity, were monitored daily following standard APHA (2023) methods. Temperature was measured using thermometer (Mercury - in - glass thermometer); pH was measured with the aid of pH meter (Model - 0009 (III)); Dissolved oxygen was measured using a Yellow Springs I (YSI) 550A hand held digital dissolved oxygen meter; Total dissolved solid was measured using a TDS meter (ERMA TDSCI) while Electrical conductivity was measured using conductivity meter calibrated with potassium chloride solution (ERMA TDSCI).

Carcass Proximate and mineral Composition of hybrid catfish fed diet supplemented with mealworm protein

Ten (10) fish per treatment was sacrificed for whole carcass proximate (moisture, ash, fat, fibre, crude protein, carbohydrate) and mineral compositions (Calcium, iron, magnesium, phosphorous, potassium) according to the methods of AOAC (2019). Fish was manually cleaned and degutted Samples were placed in a tray and kept in the oven for 24 hours at 65°C for drying. The dried sample were ground into smaller particles for analysis.

Data Analysis

The data obtained were subjected to analysis for mean and standard error. The data were analyzed using one-way analysis of variance (ANOVA). Individual means were compared using Bonferroni multiple comparison test. Differences were considered statistically significant at p<0.05. All statistical analysis and graphical presentations were performed using GraphPad prism version 9.0 software package.

RESULTS

Nutrient composition of the experimental diets

The proximate composition of the experimental diets is presented in Table 1. Moisture content varied among the diets, with the highest value recorded in diet B2 (11.45 ± 0.05) and the lowest in diet A1 (7.96 ± 2.74). There were no significant differences (p < 0.05) between diets B1 and B2 and the control diet; however, significant differences were observed among the other treatments. Crude protein content was highest in diet B2 (38.22 ± 0.02) and lowest in the control diet D (31.55 ± 0.01%), with significant differences observed among the diets (p > 0.05). Ash content did not differ significantly (p < 0.05) among the experimental diets compared with the control diet. The highest ash value was recorded in diet C1 (8.70 ± 0.10), while the lowest was observed in diet A2 (7.36 ± 0.02). Crude fat content ranged from 9.15 ± 0.13 in diet A1 to 13.23 ± 0.54 in diet C2. No

significant difference ($p < 0.05$) was observed between diet A1 and the control diet. Carbohydrate content was highest in diet A1 ($52.20 \pm 0.01\%$) and lowest in diet C1 (45.00 ± 0.01).

Growth performance of hybrid catfish fed diet supplemented with mealworm meal

The average weight gain and length gain of hybrid catfish from each dietary group were measured and the results are presented in Figure 1 and Table 2. The highest fish weight gain, length, SGR and FCE was observed in diet A1 (33.44 ± 0.44 ; 19.45 ± 1.20 ; 1.27 ± 0.06 ; 0.35 ± 0.01), while the least was observed in diet D (27.69 ± 0.23), A2 (17.50 ± 0.71), C1 and C2 (0.84 ± 0.04) and diet D (0.29 ± 0.02) (Table 2) respectively. Significant differences ($p > 0.05$) were observed in the weight, length and SGR of the experimental diets compared to the control diets. The FCR was higher in diet B1 (3.38 ± 0.04), followed by diet D (3.34 ± 0.09), while the least was in A1 (2.83 ± 0.07). Survival rate was highest in B2 and D (100.00 ± 0.00) followed by A1 and C2 (97.50 ± 3.54), while the least in C1 (92.50 ± 3.54) as shown in Table 2. The results of the condition factor (k) revealed that the highest k value was recorded in diet A2 (0.63 ± 0.01) while the least was recorded in C2 (0.46 ± 0.03) as shown in Table 2. There were no significant differences ($p < 0.05$) in the k-value between the experimental diets and the control diets. The results of the water quality parameters are presented in Table 3. There were no significant differences ($p < 0.05$) in the mean values of temperature, pH and dissolved oxygen (DO). However, significant differences were observed in the Total dissolved solid (TDS) and electrical conductivity (EC). The highest temperature was recorded in Diet C1 (26.60 ± 2.80) and lowest in A1 (25.23 ± 0.87); pH was highest in B1 and C2 (7.73) while the least was in B2 (6.57 ± 0.40); DO and TDS was highest in diet D (7.87 ± 0.35 ; 328.67 ± 68.82) while the least was in diet C2 (6.30 ± 1.23) and B1 (218.33 ± 1.53); EC was highest in C1 (272.00 ± 19.97) and lowest in B2 (182.67 ± 37.54).

Proximate composition of hybrid catfish carcass fed diet supplemented with mealworm meal

The results of the proximate composition of hybrid catfish carcass fed diet supplemented with mealworm protein are presented in Table 4. Moisture content differed significantly among treatments, with fish fed diet C1 and C2 recording the highest values (70.19 ± 0.01 and 70.69 ± 0.01 respectively), while D showed the lowest moisture content (67.84 ± 0.04). Ash content did not differ significantly ($p < 0.05$) across all treatments, ranging from 2.86 ± 0.05 (D) to 3.10 ± 0.01 (C2). Fat content showed some variation, with larvae reared on D having the highest fat content (8.67%), whereas B1, C1, and C2 recorded significantly lower fat values. Crude fibre showed no significant differences among treatments, with values ranging from 0.86 ± 0.01 to 0.94 ± 0.01 . Similarly, crude protein content did not differ significantly among treatments and ranged from 15.76 ± 0.05 to 16.20 ± 0.01 although slightly higher values were observed in larvae reared on B2 and A1. Carbohydrate content varied significantly among treatments, with B2 recording the highest value (5.09 ± 0.01) and C2 the lowest (2.17 ± 0.01).

Mineral composition of hybrid catfish carcass fed diet supplemented with mealworm meal

The results of the mineral composition of hybrid catfish carcass fed diets supplemented with mealworm protein are presented in Table 5. Calcium content differed significantly ($p < 0.05$) among treatments, with fish fed diet C1 recording the highest value (59.21 ± 0.01), followed closely by C2 (58.84 ± 0.02), while fish fed diet A2 showed comparatively lower calcium levels (52.82 ± 0.03) respectively. Iron content did not differ significantly among treatments and ranged from 0.82 ± 0.02 (D) to 0.97 ± 0.01 (C2). Similarly, magnesium content showed no significant differences across treatments, with values ranging from 30.42 ± 0.02 (D) to 32.09 ± 0.01 (A2). Phosphorus content was also not significantly affected by dietary treatments and ranged from 200.42 ± 0.00 (D) to 202.18 ± 0.02 (C2). Potassium content did not differ significantly among treatments, although slightly higher values were observed in fish fed diet B2 (261.35%) compared to the other treatments.

Table 1: Proximate Composition of the experimental diets

Composition (%)	A1	A2	B1	B2	C1	C2	D
Moisture	7.96±2.74 ^a	12.10±0.09 ^b	11.17±0.15 ^b	11.45±0.05 ^b	8.10±0.09 ^a	9.27±0.15 ^c	11.25±0.05 ^b
Ash	8.66±0.21 ^a	7.36±0.02 ^a	8.53±0.03 ^a	8.10±0.09 ^a	8.70±0.10 ^a	7.75±0.05 ^a	7.75±0.05 ^a
Fat	9.15±0.13 ^a	10.55±0.05 ^b	10.68±0.03 ^b	11.90±0.09 ^c	12.77±0.25 ^c	13.23±0.54 ^c	9.50±0.09 ^a
Crude Fiber	4.06±0.05 ^a	3.82±0.03 ^a	3.63±0.03 ^a	3.96±0.05 ^a	4.16±0.02 ^a	4.15±0.01 ^a	4.15±0.01 ^a
Crude Protein	34.80±0.10 ^a	34.22±0.02 ^a	38.06±0.05 ^b	38.22±0.02 ^b	35.02±0.02 ^c	35.55±0.01 ^c	31.55±0.01 ^d
Carbohydrate	52.20±0.01 ^a	50.72±0.02 ^a	46.82±0.02 ^b	45.58±0.02 ^c	45.85±0.01 ^c	45.00±0.12 ^c	45.01±0.02 ^c

Key: A1(2% mealworm meal reared on WB); A2 (4% mealworm meal reared on WB); B1 (2% mealworm meal reared on WB/WR); B2 (4% mealworm meal reared on WB/WR); C1 (2% mealworm meal reared on WB/PP/WR); C2 (4% mealworm meal reared on WB/PP/WR); D (control diet). Mean with the same superscript along a row are not significantly different at p<0.05.

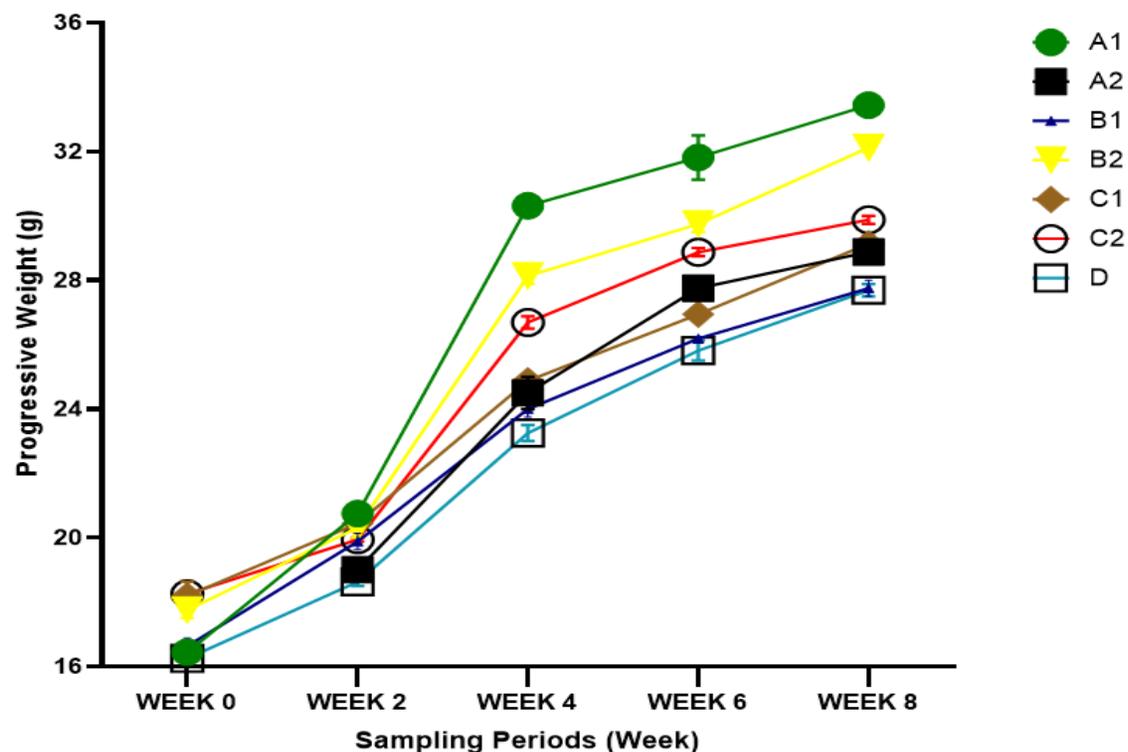


Figure 1: Progressive weight gain (g) of hybrid catfish fed diet supplemented with mealworm meal

Key: A1(2% mealworm meal reared on WB); A2 (4% mealworm meal reared on WB); B1 (2% mealworm meal reared on WB/WR); B2 (4% mealworm meal reared on WB/WR); C1 (2% mealworm meal reared on WB/PP/WR); C2 (4% mealworm meal reared on WB/PP/WR); D (control diet).

Table 2. Growth Performance of hybrid catfish fed diet supplemented with mealworm meal

Diets	Growth parameters						Condition fact (K)
	Weight gain(g)	Length (cm)	SGR (%)	FCR	FCE	Survival rate	
A1	33.44±0.44 ^a	19.45±1.20 ^a	1.27±0.06 ^a	2.83±0.07 ^a	0.35±0.01 ^a	97.50±3.54 ^a	0.58±0.07 ^a
A2	28.88±0.35 ^b	17.50±0.71 ^b	1.08±0.01 ^b	3.26±0.04 ^b	0.31±0.00 ^a	95.00±7.07 ^a	0.63±0.08 ^a
B1	27.75±0.35 ^b	18.90±1.41 ^c	0.92±0.06 ^c	3.38±0.04 ^a	0.29±0.00 ^a	95.00±7.07 ^a	0.48±0.05 ^a
B2	32.13±0.18 ^c	19.00±1.41 ^a	1.01±0.04 ^b	2.89±0.14 ^a	0.35±0.02 ^a	100.00±0.00 ^a	0.54±0.06 ^a
C1	29.13±0.35 ^d	18.50±0.14 ^c	0.84±0.04 ^c	3.19±0.09 ^b	0.32±0.00 ^a	92.50±3.54 ^a	0.47±0.01 ^a
C2	29.88±0.47 ^d	18.90±0.71 ^c	0.84±0.00 ^c	3.14±0.02 ^b	0.32±0.00 ^a	97.50±3.54 ^a	0.46±0.03 ^a
D	27.69±0.23 ^b	18.20±0.99 ^c	0.95±0.01 ^c	3.34±0.09 ^b	0.29±0.00 ^a	100.00±0.00 ^a	0.56±0.07 ^a

Key: A1(2% mealworm meal reared on WB); A2 (4% mealworm meal reared on WB); B1 (2% mealworm meal reared on WB/WR); B2 (4% mealworm meal reared on WB/WR); C1 (2% mealworm meal reared on WB/PP/WR); C2 (4% mealworm meal reared on WB/PP/WR); D (control diet). SGR=Specific growth rate; FCR= Feed conversion ratio; FCE= Feed conversion efficiency. Mean with the same superscript along a column are not significantly different at p<0.05.

Table 3. Water Quality Parameters of hybrid catfish fed diets supplemented with mealworm meal

Diets	Parameters				
	Temperature	pH	Dissolved oxygen	Total dissolved solid	Electrical conductivity
A1	25.23±0.87	6.73±0.61	7.40±0.45	258.67±31.34 ^a	223.33±4.93 ^a
A2	25.70±1.25	6.93±0.31	7.63±0.68	262.33±93.35 ^a	259.67±17.01 ^b
B1	26.50±0.78	7.07±0.49	7.20±0.44	218.33±1.53 ^b	262.33±11.15 ^b
B2	25.83±1.62	6.57±0.40	6.83±0.15	291.00±88.50 ^c	182.67±37.54 ^c
C1	26.60±2.80	6.90±0.36	6.77±0.91	248.67±26.55 ^d	272.00±19.97 ^d
C2	26.10±1.85	7.07±0.32	6.30±1.23	307.33±91.85 ^c	262.33±8.02 ^b
D	25.70±1.08	6.90±0.36	7.87±0.35	328.67±68.82 ³	260.67±4.16 ^b

Key: A1(2% mealworm meal reared on WB); A2 (4% mealworm meal reared on WB); B1 (2% mealworm meal reared on WB/WR); B2 (4% mealworm meal reared on WB/WR); C1 (2% mealworm meal reared on WB/PP/WR); C2 (4% mealworm meal reared on WB/PP/WR); D (control diet). Mean with the same superscript along a column are not significantly different at p<0.05.

Table 4. Proximate Composition of hybrid catfish carcass fed diets supplemented with mealworm meal

Composition (%)	A1	A2	B1	B2	C1	C2	D
Moisture	68.18±0.02 ^a	69.03±0.03 ^b	68.04±0.02 ^a	68.11±0.01 ^a	70.19±0.01 ^b	70.69±0.01 ^b	67.84±0.04 ^a
Ash	2.98±0.01 ^a	2.92±0.02 ^a	3.01±0.01 ^a	3.00±0.01 ^a	3.10±0.01 ^a	3.06±0.01 ^a	2.86±0.05 ^a
Fat	7.02±0.01 ^a	7.42±0.02 ^a	6.96±0.02 ^b	7.03±0.03 ^a	6.78±0.02 ^b	6.52±0.02 ^b	8.67±0.01 ^a
Crude Fibre	0.86±0.01 ^a	0.90±0.01 ^a	0.94±0.01 ^a	0.92±0.01 ^a	0.87±0.01 ^a	0.91±0.01 ^a	0.88±0.02 ^a
Crude Protein	16.19±0.01 ^a	16.04±0.01 ^a	16.16±0.02 ^a	16.20±0.01 ^a	15.97±0.01 ^a	15.87±0.03 ^a	15.76±0.05 ^a
Carbohydrate	4.28±0.01 ^a	3.26±0.01 ^b	4.21±0.01 ^a	5.09±0.01 ^a	2.97±0.01 ^c	2.17±0.01 ^b	3.44±0.04 ^a

Key: A1(2% mealworm meal reared on WB); A2 (4% mealworm meal reared on WB); B1 (2% mealworm meal reared on WB/WR); B2 (4% mealworm meal reared on WB/WR); C1 (2% mealworm meal reared on WB/PP/WR); C2 (4% mealworm meal reared on WB/PP/WR); D (control diet). Mean with the same superscript along a column are not significantly different at p<0.05.

Table 5. Mineral Composition of hybrid catfish carcass fed diets supplemented with mealworm meal

Composition (mg/100g)	Calcium	Iron	Magnesium	Phosphorous	Potassium
A1	58.03±0.03 ^a	0.90±0.01 ^a	32.03±0.03 ^a	200.96±0.02 ^a	259.02±0.03
A2	52.82±0.03 ^b	0.89±0.01 ^a	32.09±0.01 ^a	201.22±0.02 ^a	258.93±0.03
B1	56.69±0.01 ^a	0.86±0.01 ^a	30.87±0.01 ^a	200.82±0.02 ^a	256.70±0.01
B2	57.09±0.01 ^a	0.89±0.01 ^a	31.91±0.01 ^a	201.09±0.01 ^a	261.35±5.76
C1	59.21±0.01 ^a	0.94±0.01 ^a	31.22±0.02 ^a	202.05±0.05 ^a	255.23±0.02
C2	58.84±0.02 ^a	0.97±0.01 ^a	31.36±0.01 ^a	202.18±0.02 ^a	255.55±0.03
D	55.24±0.04 ^c	0.82±0.02 ^a	30.42±0.02 ^a	200.42±0.00 ^a	250.07±0.01

Key: A1(2% mealworm meal reared on WB); A2 (4% mealworm meal reared on WB); B1 (2% mealworm meal reared on WB/WR); B2 (4% mealworm meal reared on WB/WR); C1 (2% mealworm meal reared on WB/PP/WR); C2 (4% mealworm meal reared on WB/PP/WR); D (control diet). Mean with the same superscript along a column are not significantly different at $p < 0.05$

DISCUSSION

The nutritional composition of the experimental diets revealed variations in the level of moisture, ash, crude protein, crude fibre, fat and carbohydrate among the diets reflecting the differences in the substrate composition of the mealworm meal and the inclusion level. The moisture content ranging between 8-12% falls within the recommended limit for aquafeed (<12%) ensuring proper feed stability and storage (Robinson and Li, 2012). High moisture can promote microbial growth and rancidity but the levels observed in this study were within the safe range for catfish feeds.

There was no significant difference ($p < 0.05$) in the ash content between the practical diets and the control diets. This may suggest that all the diets contained adequate amounts of minerals. Similar findings (Irungu *et al.*, 2024; Lu *et al.*, 2022) have reported high ash levels for formulated catfish diets and in insect-based catfish diets (6-8%) compared to conventional feeds, attributing this to the mineral rich composition of insect exoskeleton and rearing substrates. The ash values recorded in this study are thus within the optimal range recommended for hybrid catfish diets (NRC, 2011). Since the ash content is a measure of the total amount of mineral element, this shows that the diets will serve as a suitable source of minerals to the fish.

The fat content varied among the diets with diet C2 recording the highest value. Which may influence the energy content and growth performance of the fish. The fat levels observed in this study are higher than the range (7-8% and 5-6%) reported by previous studies (Adamu *et al.*, 2021); Gebremichael *et al.*, 2023; Kolawole *et al.*, 2023) for African and Hybrid catfish fed insect meal-based diets. This shows that diet C (diet supplemented with mealworm reared on WB/PP/WR) will provide a better source of fat which may enhance growth performance. In addition, the retention of high fat levels in the diets suggests that the coating process did not compromise feed quality, maintaining the nutritional value essential for optimal growth performance.

The fiber values (3.63-4.15%) align with those recommended for catfish diets as excessive fiber more than 8-12% in fish feed lowers feed digestibility of nutrient and causes slow growth (De Silva *et al.*, 1991). The presence of fiber in feed improves binding

and moderate the passage of feed through the alimentary canal (Ayuba and Iorkohol, 2012).

Protein levels were generally high across treatments with diet B1 and B2 recording the highest crude protein content which could be linked to the high protein content in mealworms reared on WB/WR (Oladunni *et al.*, 2025). The protein range recorded in this study is consistent with the optimal dietary protein requirement (30-40%) for hybrid and African catfish juveniles (Adebayo *et al.*, 2017; Dauda *et al.*, 2022). This confirms that the supplemented diets provided adequate protein for maintenance and growth. Protein is important in ensuring adequate growth and well-being of fish (Suphada and Anut, 2012). The values obtained in this study are also in line with the values (35-47%) reported by Kolawole *et al.* (2023) when hybrid catfish diets were supplemented with cockroach meal. This shows that mealworm reared on a mixture of WB/WR will provide a better source of protein.

Carbohydrate levels reported in this study was higher than the recommended limit (30-35%) for balanced catfish diets (Aiyelari and Adeyeye, 2022) with diet A recording the highest and significantly different when compared with the control diet. This shows that the diet A (diet supplemented with mealworm meal reared on WB) will serve as an adequate source of energy for high quality hybrid catfish feeds.

The mealworm-based diets supported superior growth compared with the control. This is likely due to the high protein, balanced amino acid profile, and additional nutrients in the mealworm meal. Among the experimental diets, Diet A1 (2% mealworm meal reared on wheat bran), Diet B2 (4% mealworm meal reared on WB/WR), and Diet C2 (4% mealworm meal reared on WB/PP/WR) produced significantly higher weight gain, length, and SGR than the control. Fish fed Diet A1 (wheatbran) required a low inclusion of 2% mealworm protein to improve the growth performance of the fish. While those reared on fruit-waste substrates (B2 and C2) required higher inclusion of 4% for optimal growth. This suggests that the nutritional value of the larvae is significantly influenced by the substrate type, which may have affected the nutrient contribution of the diets. Consequently, a higher inclusion level was required for larvae reared on fruit waste substrates to produce comparable growth. These demonstrate how crucial

the substrate used for larval rearing is in assessing the effectiveness of mealworm inclusion in aquafeeds. This is also in line with previous studies (Jeong *et al.*, 2020; Herawati *et al.*, 2025) showing improved growth in fish fed mealworm-based diets.

The weight gain was highest in fish fed Diet A1 despite its moderate protein level, while Diet B2 with the highest protein content, required a higher inclusion level to obtain similar values. Although Diet C2 contained slightly lower crude protein than Diet B2, the relatively higher lipid and carbohydrate contents may have contributed additional dietary energy, which may have improved nutrient utilization and supported growth performance. These findings support the view that growth performance is influenced by a combination of nutrient composition, digestibility, palatability, and mineral content rather than crude protein alone (Ferri *et al.*, 2024; Gebremichael *et al.*, 2023; Langston *et al.*, 2024; Ng *et al.*, 2001). This finding is consistent with previous studies (Bonelli *et al.*, 2020; Jeong *et al.*, 2020; Ng *et al.*, 2001; Padmanabha *et al.*, 2020) showing that insect nutrient composition and growth performance are strongly shaped by rearing substrates and dietary inclusion rates, even across different insect species and fish species.

Although diets B2 and C2 showed indications of improved nutrient utilization at the 4% inclusion level, the SGR values obtained in this study (0.84–1.27) were lower than those reported in previous studies (Kolawole *et al.*, 2023) for hybrid catfish fed insect-based diets, but higher than values reported by Adamu *et al.*, (2021) for cockroach meal-based diets. Similarly, FCR values (2.83–3.35) exceeded those reported for African catfish fed diets formulated to meet optimal protein requirements, where lower FCR values are typically associated with more efficient feed utilization (Stone, 2024). The relatively higher FCR values observed in this study compared with previous studies may be linked to differences in diet formulation and experimental conditions, which can influence feed utilization efficiency. This also supports the findings of Sandor *et al.* (2022) and Bake *et al.* (2023) who reported that moderate inclusion levels of alternative protein sources, such as mealworm meal, can effectively enhance growth performance in catfish without adverse effects on feed efficiency or survival (Bake *et al.*, 2023; Sándor *et al.*, 2022).

The condition factor (K) was low across all treatments but are in line with the values reported in previous studies on juvenile hybrid catfish reared over short experimental periods. Because, during the early life

stages many fish species records a low K-values because they allocate energy toward skeletal and structural development which leads to a rapid increase in length compared to weight even when the weight gain is high (Froese, 2006). The similarity of K across treatments (all within 0.41–0.54) suggests that the k-value is low and the differences in diet or rearing conditions influenced growth rate but did not produce large disparities in overall somatic condition. Previous studies (Jimoh *et al.*, 2023; Keyombe *et al.*, 2015; Sadauki *et al.*, 2023) have reported similar growth patterns during early development, where the fish increase rapidly in length but gain weight more slowly, resulting in relatively low body mass compared to body size. This disproportionate growth leads to condition factors below one during the first 2–3 months of culture. The consistently low but similar K-values in this study therefore indicate that the fish were undergoing normal juvenile growth patterns rather than experiencing nutritional stress or poor health.

The water quality parameters recorded throughout the experimental period fall within ranges reported as acceptable for *Clarias gariepinus* and hybrid catfish (*Clarias × Heterobranchus*) (Iloba *et al.*, 2020; Sándor *et al.*, 2022), which indicates that the supplemented diets containing mealworm meal did not adversely affect the rearing environment. The consistency of water-quality parameters across the treatments suggests that rearing conditions were favourable. The pH values were in line with the normal range reported for the growth and survival of *Clarias gariepinus* as reported by Marimuthu *et al.* (2019), as extreme pH below 4.5 or above 9.0 may reduce the survival of the fish. DO levels in this study are above 5 mg/L which are generally considered sufficient in supporting normal metabolic activity in African catfish rearing (Omitoyin *et al.*, 1998). The TDS and EC values were consistent with previous studies by Nguka *et al.* (2025) which indicates that the diets containing the insect protein did not significantly alter the water quality.

The inclusion of mealworm meal in the diets did not significantly affect the carcass proximate composition of the fish which shows that the diets did not alter the biochemical characteristics of the fish. Minimal variations were observed in the moisture content across the diets. However, the values were lower than the range (72-75%) reported in previous studies such as Ibhaddon *et al.* (2015), Solomon (2018) and Chaijan *et al.* (2024). Which could be due to the drying technique used. High moisture content may increase microbial growth and leads to deterioration which

ultimately lead to a low shelf life (Tavares *et al.*, 2021). However, the moisture levels observed in this study suggests that the fish carcass is less susceptible to microbial spoilage. The ash content exceeded the range of 1.74-2.20% reported by Jeong *et al.* (2020) for rainbow trout fed mealworm meal and also those reported for wild and farmed catfish (Ibhadon *et al.* 2015; Elaigwu, 2019). Similarly, higher ash values have been reported in Atlantic salmon fed mealworm meal over a 12 weeks study period (Habte-Tsion *et al.* (2024). This indicates that the mealworm meal may have enhanced the mineral composition in the fish and the fish can serve as a good source of minerals. The fat content was lower than the values reported in previous studies by Jeong *et al.* (2020) and Adamu *et al.* (2021) but exceeded the range (1.15-2.08%) considered acceptable for catfish (Ibhadon *et al.*, 2015). The crude fiber levels were higher than the range of values (0.6-5.0) reported in previous studies by Elaigwu (2019), Adamu *et al.* (2021) and Habte-Tsion *et al.* (2024). The protein content was lower than those reported in previous studies (Elaigwu, 2019; Adamu *et al.* 2021) which may reflect minor variations in feed preparation, sample handling, and analytical procedures, but the growth and nutrient utilization data indicate that the diets were adequate for supporting juvenile hybrid catfish performance.

However, the values are similar to the range (14.2–15.3%) reported by Jeong *et al.* (2020) for rainbow trout fed mealworm meal. The values reported in this study also were more than those reported by Ibhadon *et al.* (2015) for wild and farmed catfish which indicates that the fish can serve as an excellent protein source. The carbohydrate levels were significantly different across the diets and are higher than <0.5% reported by FAO (1999) for fish flesh. However, differences could be due to age, feeding regime and environmental conditions (Ahmed *et al.*, 2022).

The levels of calcium, a key mineral important for growth, muscle contraction and blood clotting were higher than the values (16.13mg/100g and 12.3mg/100g) reported by Aremu *et al.* (2021) and Tsegay *et al.* (2016). This indicates that the fish can serve as a good source of calcium which can also support skeletal development and metabolic functions. Magnesium levels were lower than the values (59.9mg/100g) reported by Tsegay *et al.* (2016). Phosphorous which is essential for energy metabolism and bone mineralization were stable at approximately 200 mg/100g aligning with previous studies on rainbow trout and Atlantic salmon fed diets containing mealworm meal (Habte-Tsion *et al.*

2024; Jeong *et al.* 2020). Potassium was the most abundant mineral in line with previous studies by Njinkoue *et al.* (2016) and Nölle *et al.* (2020) highlighting its role in maintaining osmotic balance cellular homeostasis and nerve transmission. Iron is essential for hemoglobin synthesis and oxygen transport. The concentrations reported in this study were lower than the ranges (3-11mg/100g) reported by Ogungbenle and Otemuyiwa (2018). Which indicates that the mealworm protein did not interfere with the mineral composition of the fish.

CONCLUSION

The findings of this study indicates that the composition of the diet as well as the substrate type influenced the growth performance, nutrient content and mineral composition of the fish. While there were variations in the protein, ash, fiber and carbohydrate content, fish fed Diet A1 (2% mealworm reared on 100% wheat bran) achieved the highest growth, followed by Diet B2 (4% mealworm reared on a mixture of wheat bran and watermelon rind) and Diet C2 (4% mealworm reared on wheat bran, pineapple peels, and watermelon rind) indicating that optimal performance depends on a balanced nutrient profile rather than a single component. Carcass analysis showed efficient nutrient utilization across all treatments, and the mineral content (Ca, Mg, P, K, Fe) remained within reported ranges, demonstrating that mealworm supplementation did not compromise flesh quality. Therefore, the study supports the use of fruit-wastes and other agricultural by-products as substrate for the production of mealworm and as components for sustainable aquaculture feeds.

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Conflict of interest:

There is no conflict of interest to declare.

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