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Growth performance and carcass composition of African catfish (*Clarias gariepinus* Burchell, 1822) fed on black soldier fly (*Hermetia illucens* Linnaeus, 1758) larvae based diets

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A 12-week feeding trial was conducted to evaluate the effects of replacing fishmeal with black soldier fly larvae (BSFL) meal on growth performance and carcass composition of African catfish fingerlings. Five isonitrogenous (40% CP) diets of 0 (Control), 25, 50, 75 and 100% fishmeal with BSFL were used in triplicate. A randomized complete block design was used, and 600 fingerlings (0.46±0.02g) were randomly selected and stocked at a rate of 40 fingerlings in 15 plastic tanks respectively. Results showed that the treatment diets significantly ($P<0.05$) affected growth indexes, feed utilisation indices, and carcass composition of fish. Furthermore, 25% fishmeal could be replaced by BSFL meal without significantly reducing growth indexes and feed utilisation indices. However, water quality and condition factors between treatments were not significantly ($P>0.05$) affected by the diets. Decreased concentration of crude protein, ash, nitrogen free extracts in carcass composition of fingerlings with corresponding increase in dietary BSFL meal inclusion was observed. Increasing inclusion levels of BSFL meal and decreasing levels of fishmeal increased the concentration of ether extracts and fibre contents of the body composition. Therefore, BSFL meal protein can be used to partially replace fish meal up to 25% to improve growth performance and feed utilisation.

Key words: Feed utilization, fishmeal, indices, insect meal, proximate analysis.

INTRODUCTION

Aquaculture is one of the fastest growing agricultural industries globally, contributing to food security as a rich source of high-quality proteins containing all essential amino acids, minerals, and micronutrients such as zinc, iron, omega-3 fatty acids, and vitamins (Golden et al., 2016). Globally, the annual human per capita fish

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consumption is estimated at 20.5kg, of which, aquaculture contributes 46% of the total production and 52% of fish consumed by humans (FAO, 2020). In spite of the significant contribution of aquaculture, fish production has not met the demand due to an increase in the human population (Belghit et al., 2018), use of wild fish for feed production, climate change, diseases (Naylor et al., 2021), and inadequate high quality and affordable fish feeds (Munguti et al., 2021). One of the most important aspects required to increase aquaculture production while ensuring the industry's sustainability is fish nutrition. Thus the formulation and production of good quality and affordable feeds are needed, to ensure fast growth and survival and wellness of cultured fish without causing environmental pollution (Limbu et al., 2022). Nutrition is a key component in aquaculture, which under current production economics accounts for more than 50 to 70% of the total variable costs (Teye-Gaga, 2017) depending on the intensity of the used culture system (Limbu and Jumanne, 2014). For many decades, fishmeal has been traditionally used as the primary protein ingredient in aquaculture feeds (Abdel-Tawwab et al., 2020). This is because of its balanced essential amino acids, easy digestibility, and palatability, and its desirable attributes in enhancing nutrient digestion and absorption (Guedes et al., 2015). However, fishmeal is becoming expensive, which leads to its decreasing availability in aquafeeds (Rawski et al., 2020). Due to the direct competition for human consumption (Xiao et al., 2018), the availability of fishmeal has become relatively limited for aquaculture and there has been a drop in wild fish catches (Limbu et al., 2022). Fishmeal is also used for formulating other livestock feeds, especially for the pig and poultry industry (Kirimi, 2019), thereby, exacerbating the situation. The continued use of fishmeal threatens the sustainability of the aquaculture industry from both an environmental and economic perspective (Tacon and Metian, 2008). It is believed that fishmeal is no longer capable of supporting the development of the aquaculture industry in the near future. Therefore, there is an urgent need to seek alternative protein sources to replace fishmeal for sustainable aquafeed production (Limbu et al., 2022). In search of alternative quality protein for fish feeds, much attention has been paid to the use of insects (Limbu et al., 2022). Insects have the required nutritional quality (Nowak et al., 2016) and are consumed naturally by many animals, including fish, wild birds, and free-ranging poultry (Fiaboe and Nakimbugwe, 2014). In this regard, the larvae of the Black Soldier Fly (*Hermetia illucens*) larvae (BSFL) is one of the most promising alternative protein sources that can replace fishmeal as a low-cost nutrient-rich ingredient for aquafeeds production (Caimi et al., 2021). The BSFL is capable of converting organic waste into food (Wang and Shelomi, 2017), generating value and closing nutrient loops as it reduces organic pollution and subsequent management costs, as compared to other insects (Chia et al., 2019). BSFL meal has been used successfully to replace fishmeal in diets for various fish species, such as the Nile tilapia (*Oreochromis niloticus*) (Limbu et al., 2022); Jian carp (*Cyprinus carpio* var. Jian) (Zhou et al., 2018), and Rainbow trout (*Oncorhynchus mykiss*) (Terova et al., 2019). However, there is a paucity of information regarding the use of BSFL meal on the growth and carcass composition of African catfish (*Clarias gariepinus*), which is one of the common fish species cultured in fresh water bodies. The African catfish is one of the choice culture species due to its high demand, rapid growth and high productivity, and fair prices (Engle et al., 2022). The present study was therefore, conducted to assess the use of BSFL meal as a partial or total replacement for dietary fishmeal on the growth performance and carcass composition of *C. gariepinus*. Once the in-depth knowledge of the impact of BSFL on African Catfish production is determined, the aquaculture industry can adopt the suitable formulation, commercialize it and then thrive, particularly in the smallholder sector.

MATERIALS AND METHODS

Study site

The study was carried out from March to June 2022 under greenhouse conditions at Jaramogi Oginga Odinga University of Science and Technology (JOOUST), fish farm, Kenya. The geographical coordinates of the university are 0°05'38.0"S, 34°15'31.0"E (Latitude:-0.093889; Longitude: 34.258611). The area experiences temperature ranges of 15-30°C, 57-87% relative humidity and 800-2,000 mm annual rainfall (Achonga et al., 2011).

Ethical statement

The protocol of this experiment (ERC 29/4/22-23) was approved by the Ethics Committee of the Jaramogi Oginga Odinga University of Science and Technology (JOOUST). Fish were handled with maximum care to limit the risks of unnecessary stress and mortality that may result from improper handling.

Source of feed ingredients

Black soldier fly larvae were sourced from the JOOUST Insectary. The BSFL was stored in bags at room temperature until time of use. The other feed ingredients (fish meal, cassava, rice bran) were sourced from local markets. The selection of the ingredients was based on their local availability in sufficient amounts, cost, need for disposal and nutrient profile (Nyakeri, 2018). Preference was given to those (cassava and rice bran) that are by-products or waste products, whose incorporation in feeds could also enhance best practices in natural resource use and waste management (Madu et al., 2003). Vitamins and mineral premixes were sourced commercially, and supplemented in the feed in the required amounts to ensure the final feed products meet the National Research Council (NRC) recommended amounts for African catfish (NRC, 1993).

Proximate analysis of ingredients, experimental diets and fish carcass

Samples of the feed ingredients, experimental diets (Table 1) and fish carcass (Table 4) were analyzed in triplicate, according to

Table 1. Ingredients and proximate compositions of the experimental diets (percentage of dry matter basis) and proximate compositions (mean±SE).

Variable	Experimental diets composition				
	BSFL 0%	**BSFL 25%**	**BSFL 50%**	**BSFL 75%**	**BSFL 100%**
Ingredients					
Fishmeal	50.44	37.83	25.22	12.61	0.00
BSFL meal	0.00	20.15	40.3	60.45	80.6
Rice bran	18.72	15.76	12.79	9.82	6.85
Cassava flour	28.84	24.26	19.69	15.12	10.55
Vitamin-mineral premix	2.00	2.00	2.00	2.00	2.00
Total nutritional level	100.00	100.00	100.00	100.00	100.00
Proximate composition					
Dry matter	91.68±0.07^{c}	91.73±0.09^{c}	92.13±0.10^{bc}	92.24±0.14^{ab}	92.61±0.08^{a}
Ash	15.30±0.03^{b}	16.16±0.10^{a}	14.21±0.06^{c}	13.40±0.04^{d}	12.27±0.06^{e}
Ether extracts	8.36±0.42^{a}	8.15±0.44^{a}	8.39±0.67^{a}	8.26±0.22^{a}	8.37±0.19^{a}
Crude protein	39.72±0.39^{a}	40.34±0.34^{a}	40.17±0.14^{a}	39.75±0.07^{a}	40.39±0.35^{a}
Crude fibre	6.32±0.10^{c}	6.98±0.02^{b}	7.30±0.08^{b}	8.33 ± 0.03^{a}	8.31±0.09^{a}
Nitrogen free extracts	30.31±0.67^{a}	28.37±0.65^{a}	29.94±0.78^{a}	30.26±0.22^{a}	30.67±0.40^{a}

Experimental diets included different levels of Black soldier fly larvae (BSFL) meal replacement at 0% BSFL meal + 100% fishmeal (Control diet); 25% BSFL meal + 75% fishmeal; 50% BSFL meal + 50% fishmeal; 75% BSFL meal + 25% fishmeal and 100% BSFL meal + 0% fishmeal.

Source: Data from the current study.

standard AOAC methods (AOAC, 1998). All samples were dried at 105°C to determine moisture content. Ash was determined by a combustion method at 550°C in a muffle furnace, while crude protein was measured by nitrogen analysis (N x 6.25) using the Kjeldahl method. Ether extract content was determined by the Soxhlet extraction method with petroleum ether (40–60°C, boiling point). Crude fibre was determined by digesting dried lipid-free residue with 1.25% sulphuric acid, 1.25% sodium hydroxide and calcined. The carbohydrates (nitrogen free extracts) were determined as 100 - (moisture content + crude protein + crude fat + ash + fibre).

Preparation of experimental diets

Formulation and proximate compositions of the experimental diets are shown in Table 1. Five isonitrogenous (40% crude protein) diets were used to replace fish meal protein with BSFL meal at 0% (BSFL 0%), 25% (BSFL 25%), 50% (BSFL 50%), 75% (BSFL 75%) and 100% (BSFL 100%). Fish meal, cassava meal and rice bran were the major feed ingredients in the experimental diets. A semi-commercial stainless steel feed mixer Model M20A KITMA China, at 100 rpm operated at 220-240 Volts was used for feed mixing. All the ingredients were mixed thoroughly for three minutes to get a homogenous mixture. A 25% clean water mixture with vitamin-mineral premix was added into the feed, and preceded with mixing for another three minutes to form dough. The dough was pressed through a manual wet mincing machine at high pressure to produce 2 mm pellets. The pellets were dried in the sun for one day, and then packed in labelled water proof and airtight bags to prevent absorption of moisture and growth of moulds. The pellets were finally crushed to approximately 0.5 mm to facilitate ingestion by the juvenile fish.

Source of African catfish and experimental setup

Six hundred mixed sex *C. gariepinus* fingerlings (mean weight 0.46 ± 0.02 g) used in this experiment were procured from the Tigoi Fish Farm in Vihiga County, Western Kenya. The Catfish fingerlings were transported to the study site in well-oxygenated polythene bags.The African catfish fingerlings were acclimatised for two weeks before the start of the feeding trial. A randomized completely block design (RCBD) was used to assign three circular plastics tanks per treatment. Fish were randomly distributed among the 15 circular plastic tanks at 40 fish per tank. Each tank had a capacity to hold 250 L of water. Fresh dechlorinated water was used to fill all tanks throughout the trial up to 80% of the total tank volume to avoid fish jumping out. During the culture period, 75% of water was replaced by reducing the water level up to 25% of the total size of the tank by volume and replenishing with fresh dechlorinated water every two weeks to maintain water quality at optimum levels. During the feeding trial, a multi-parameter water quality meter (YSI 550A) was used to measure the dissolved oxygen and temperature in the tanks. Water pH was also measured using a portable waterproof pH meter (ATC 618).

Feeding trial and data collection

Before stocking, the fingerlings in each tank were weighed using an electronic weighing balance (Scout Pro Balance, Ohaus) to determine their initial mean weight (g). The BSFL diets were randomly assigned to the experimental tanks in three replicates. The fingerlings were fed twice a day at 6% fish body weight between 08:00 – 09:00 and 16:00 – 17:00 hours. From the beginning of the feeding trial to completion at 84 days, 10 fingerlings per replicate were randomly sampled and weighed every two weeks and the amount of fish feed was adjusted according to fish body weight.

Determination of growth performance, feed utilization and condition factor

Growth performance of fish fed different percentages of BSFL meal protein replacement were determined for Mean Weight Gain (MWG), Specific Growth Rate (SGR), Feed Intake (FI), Feed Conversion Ratio (FCR), Protein Intake (PI), Protein Efficiency Ratio (PER) and Condition Factor (K_n) using the following equations, 1 to 7, respectively:

$$\text{Mean weight gain (\%)} = \frac{\text{Final body weight (g)} - \text{Initial body weight (g)}}{\text{Initial body weight (g)}} \text{x} 100 \quad (1)$$

$$\text{Specific Growth Rate (\%)} = \frac{\text{Ln final body weight} - \text{Ln initial body weight}}{\text{Number of feeding days}} \text{ x } 100 \quad (2)$$

$$\text{Feed Intake} = \frac{\text{Total feed intake per fish (g)}}{\text{Total number of days for the experiment}} \text{x} 100 \quad (3)$$

$$\text{Feed Conversion Ratio} = \frac{\text{Weight of feed fed (g)}}{\text{Weight gain of fish (g)}} \quad (4)$$

$$\text{Protein Intake} = \frac{\text{Total feed consumed x Crude protein feed}}{100} \quad (5)$$

$$\text{Protein Efficiency Ratio} = \frac{\text{Weight gain of fish (g)}}{\text{Protein intake}} \quad (6)$$

$$\text{Condition Factor } (K_n) = \frac{W_o}{a \times L^b} = \frac{W_o}{W_p} \quad (7)$$

Where; W_o = Weight of fish observed in grams; W_p = Weight of the fish predicted from the equation $W = aL^b$; L = The total length of the fish in centimetres; and b = The exponent value obtained from the length-eight equation formula and a = constant in the length-weight relationship.

Statistical analyses

Data obtained from each experimental diet consisting of random variables was tested using one-way ANOVA for Mean Initial Weight (MIW; g), Mean Final Weight (MFW; g), Mean Initial Length (MIL; cm) and Mean Final Length (MFL; cm), water quality parameters and carcass composition parameters were tested using one-way ANOVA, to test the significant difference. Mean separation between treatments was determined by Post hoc test at $\alpha = 0.05$ and results for ANOVA were expressed as mean ± standard error, while medians and average ranks for condition factors were separated using Kruskal-Wallis test. Other growth performance parameters such as Mean Weight Gain (MWG; %), Specific Growth Rate (SGR; %), Feed Conversion Ratio (FCR), Protein Intake (PI) and Protein Efficiency Ratio (PER) were not tested statistically since they are indices they did not meet the requirements for parametric analysis (they had single output/values). Growth in length and weight were analyzed by comparing their increase against time (growth rate) to provide an objective way for comparing the slopes for the different treatments using and finally applying a General Linear Model (GLM) with treatment categorical variable. All analyses were conducted using Minitab Ver 17.0 and Statgraphics Ver 16.

RESULTS

Growth performance, feed utilisation and condition factor

Results showed that the MFW and MFL of 25% were significantly higher than all the other treatments ($F_{0.05, 4}$=33.87, *P*-value = 0.001) and ($F_{0.05, 4}$=52.58, *P*-value = 0.001), respectively. The values of MWG (2789), SGR (4.00), FI (10.77), PI (4.31) and K_n (1.0049) for BSFL 25% gave a better performance than the other treatments. The values of FCR (0.72) and PER (3.48) for BSFL 0% gave a better results than other treatments (Table 2).

Fish growth regression slopes in weights

The Generalised Linear Model (GLM) of growth in weight with the diets as categorical treatments showed that there was adequate evidence that at least one of the slopes was significantly different (Figure 1). Multiple comparison using Fisher's Least Significant Difference (LSD) identified four homogenous groups. A visual examination of the plot showed that BSFL 25% was the best performing formulation, while BSFL 100% showed the poorest performance with an average growth rate of 0.7% per day as compared to BSFL 25% with a 1.27% growth rate per day.

Fish growth regression slopes in lengths

The Generalised Linear Model (GLM) of growth in weight with the diets as categorical treatments showed that there was adequate evidence that at least one of the slopes was significantly different Figure 2. Multiple comparison using Fisher's Least Significant Difference (LSD) identified four homogenous groups. A visual examination of the plot showed that BSFL 25% was the best performing formulation while BSFL 100% showed the poorest performance with an average growth rate of 0.07% per day as compared to BSFL 25% with a 1.3% growth rate per day.

Water quality parameters

The results of Table 3 showed that all the water quality parameters: temperature, pH, dissolved oxygen, ammonia and nitrate were statistically similar with $F_{0.05, 4}$=1.53, *P*-value = 0.001; $F_{0.05, 4}$=0.001, *P*-value = 0.001; $F_{0.05, 4}$=0.01, *P*-value = 0.001; $F_{0.05, 4}$=0.64, *P*-value = 0.001 and $F_{0.05, 4}$=0.55, *P*-value = 0.001, respectively.

Carcass composition

Results of Table 4 indicated that dry matter, ash, ether extracts, crude protein, crude fibre and nitrogen free extracts of fish fed with the experimental diets were significantly different across all the treatments with $F_{0.05, 4}$=147.97, *P*-value = 0.001; $F_{0.05, 4}$=128.44, *P*-value = 0.001; $F_{0.05, 4}$=882.25, *P*-value = 0.001; $F_{0.05, 4}$=98.77, *P*-value = 0.001; $F_{0.05, 4}$=653.84, *P*-value = 0.001; and $F_{0.05,}$

Table 2. Growth performance, feed utilisation and condition factor of African catfish, *Clarias gariepinus* fingerlings fed black soldier fly based diets for twelve weeks.

Parameter	Dietary treatment						
	BSFL 0%	**BSFL 25%**	**BSFL 50%**	**BSFL 75%**	**BSFL 100%**	**F-Statistic**	**P-Value**
ANOVA (µ±SE)							
MIW (g)	0.41±0.02^{a}	0.50±0.02^{a}	0.48±0.02^{a}	0.45±0.02^{a}	0.47±0.02^{a}	2.21	0.071
MFW (g)	11.89±0.46^{b}	14.37±0.69^{a}	10.14±0.60^{b}	7.99±0.58^{c}	6.27±0.35^{c}	33.87	<0.001
MIL (cm)	4.04±0.08^{a}	4.24±0.07^{a}	4.17±0.08^{a}	4.18±0.08^{a}	4.11±0.08^{a}	0.96	0.433
MFL (cm)	11.96±0.16^{ab}	12.73±0.20^{a}	11.34±0.22^{b}	10.22±0.32^{c}	8.22±0.28^{d}	52.58	<0.001
Kruskal-Wallis (median(rank))							
						H-Statistic	**P-Value**
MWG (%)	2775	2789	2019	1674	1231		
SGR (%)	4.00	4.00	3.64	3.42	3.08		
FI (g)	9.51	10.77	8.43	6.07	4.17		
FCR	0.83	0.78	0.87	0.81	0.72		
PI	3.81	4.31	3.37	2.43	1.67		
PER	3.02	3.22	2.86	3.11	3.48		
K_n	1.0017 (540.7)	1.0049 (575.9)	0.9962 (540.9)	0.9942 (532.1)	0.9466 (437.9)	24.51	<0.001

^{a,b,c,d} Means with different superscripts in the same row are different from each other (P<0.05). MIW: mean initial weight; MFW: mean final weight; MIL: mean initial length; MFL: mean final length; MWG: mean weight gain; SGR: specific growth rate; FI: feed intake; FCR: feed conversion ratio; PI: protein intake; PER: protein efficiency ratio; K_n: condition factor.
Source: Data from the current study.

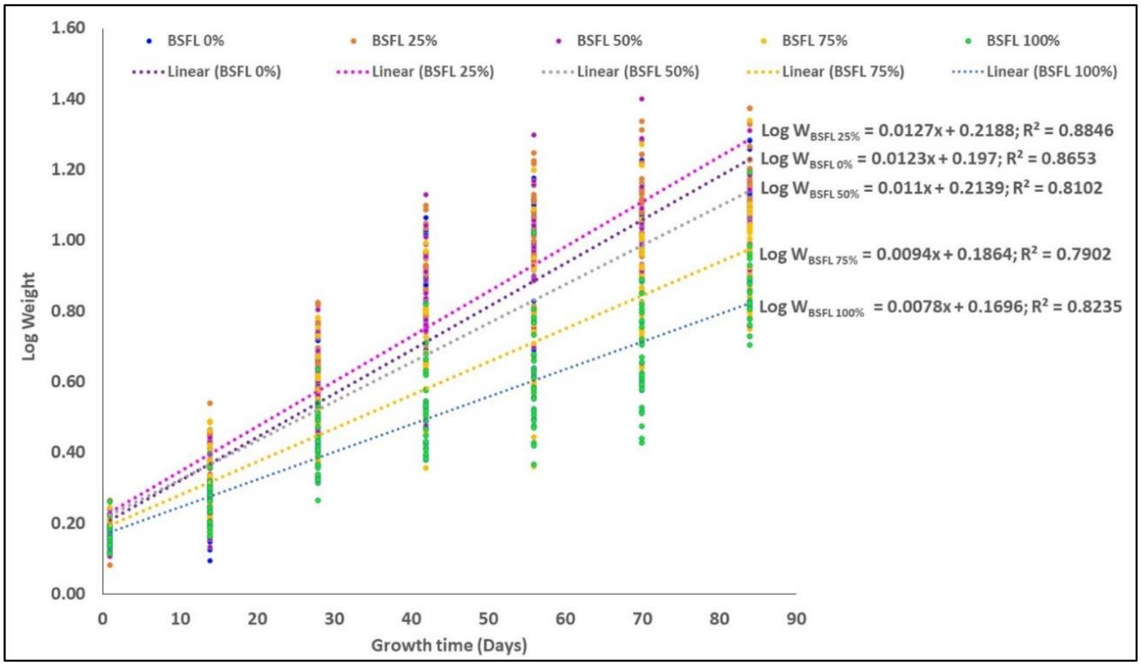

Figure 1. Regression slopes of Log Weight by days of African catfish, *Clarias gariepinus* fed BSFL based diets.
Source: Data from the current study.

$_4$=41.28, *P*-value = 0.001, respectively. However, the results also showed that the crude protein, ash and nitrogen free extracts contents of BSFL 0% performed better than the other treatments. The results also indicated that BSFL 0% had inferior dry matter and crude fibre contents than all other treatments.

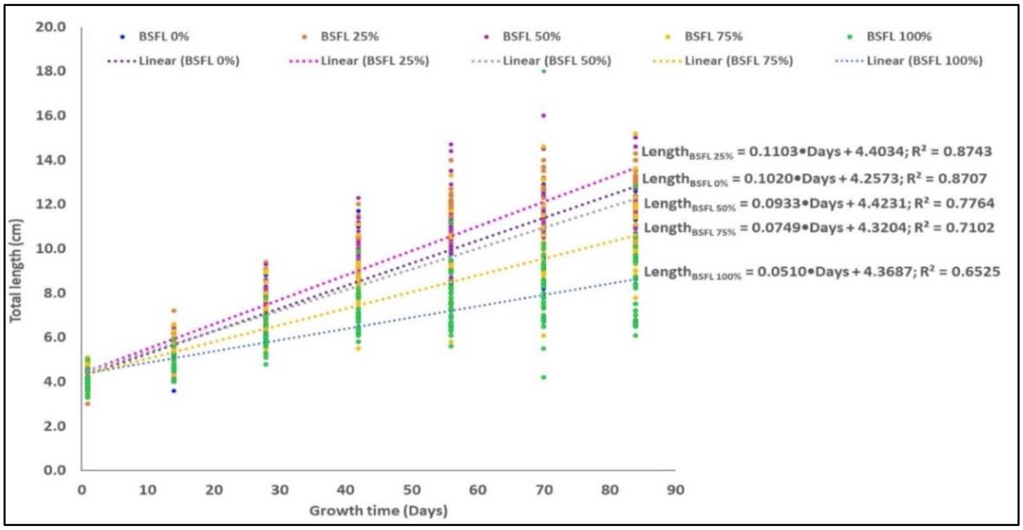

Figure 2. Regression slopes of length by days of African catfish, *Clarias gariepinus* fed BSFL based diets.
Source: Data from the current study.

Table 3. Physico-chemical water quality parameters recorded during the study.

Parameter	Dietary treatment						
	BSFL 0%	BSFL 25%	BSFL 50%	BSFL 75%	BSFL 100%	F-Value	P-Value
Temperature	28.83±0.10^{a}	28.56±0.10^{a}	28.58±0.10^{a}	28.58±0.10^{a}	28.74±0.10^{a}	1.53	0.190
pH	7.49±0.02^{a}	7.48±0.02^{a}	7.48±0.02^{a}	7.49±0.02^{a}	7.48±0.02^{a}	0.01	1.000
Dissolved oxygen (mg/L)	3.27±0.08^{a}	3.28±0.08^{a}	3.28±0.08^{a}	3.27±0.08^{a}	3.27±0.08^{a}	0.001	1.000
Ammonia	0.41±0.07^{a}	0.40±0.07^{a}	0.46±0.09^{a}	0.47±0.09^{a}	0.32±0.05^{a}	0.64	0.639
Nitrate	0.02±0.010^{a}	0.02±0.01^{a}	0.02±0.01^{a}	0.02±0.01^{a}	0.02±0.01^{a}	0.55	0.700

Mean values with similar superscripts in the same row are not different from each other ($P>0.05$).
Source: Data from the current study.

Table 4. Proximate composition of the African catfish, *Clarias gariepinus* fingerlings fed black soldier fly based diets.

Parameter	Experimental fish carcass						
	BSFL 0%	BSFL 25%	BSFL 50%	BSFL 75%	BSFL100%	F-Value	P-Value
Dry matter	97.29±0.02^{c}	98.11±0.02^{a}	97.06±0.001^{b}	97.06±0.01^{e}	97.13±0.01^{d}	1427.97	<0.001
Ash	14.91±0.24^{a}	14.00±0.06^{b}	13.34±0.15^{c}	13.59±0.09^{bc}	10.69±0.07^{e}	128.44	<0.001
Ether extract	20.00±0.08^{e}	22.66±0.03^{d}	24.24±0.16^{c}	26.05±0.16^{b}	30.34±0.16^{a}	882.25	<0.001
Crude protein	58.18±0.08^{a}	56.66±0.40^{b}	55.31±0.43^{b}	52.87±0.13^{c}	50.12±0.38^{d}	98.77	<0.001
Crude fibre	1.36±0.04^{e}	2.41±0.02^{d}	3.47±0.04^{c}	5.35±0.13^{b}	7.54±0.16^{a}	653.84	<0.001
Nitrogen free extracts	5.55±0.21^{a}	4.27±0.45^{b}	3.65±0.19^{b}	2.16±0.23^{c}	1.31±0.12^{c}	41.28	<0.001

^{a,b,c,d,e} Means with different superscripts in the same row are different from each other ($P<0.05$).
Source: Data from the current study.

DISCUSSION

Growth performance, feed utilisation and condition factor

The results of the present study illustrated that the diet in which 25% of fishmeal protein has been replaced by BSFL meal gave rise to the best results without negative consequences for growth performance, when compared to all the other treatment diets. These results are in agreement with those of previous studies which suggested an optimum fish meal replacement level of

25% using insect meal (Teye-Gaga, 2017; Xiao et al., 2018) in different aquaculture species. Our finding strongly agrees with that of Xiao et al. (2018), who observed that replacing fishmeal with 25% BSFL produced the best results in growth and immune index of yellow catfish (*Pelteobagrus fulvidraco*). These results also strongly agree with those of a previous study which indicated that BSFL could replace up to 25% fishmeal in the diet of Nile tilapia (*Oreochromis niloticus*) without adverse effects on growth performance (Teye-Gaga, 2017). On the contrary, our results for growth performance and feed utilization differ from those of Limbu et al. (2022), who recorded high growth performance and feed utilization in Nile tilapia (*Oreochromis niloticus, L.*) fry that were given diets supplemented with BSFL meal up to 75%.

When replacing fishmeal with BSFL meal from 50% to 100% in fish diets, growth of *C. gariepinus* was strongly suppressed, while FI and PI reduced as well as increased FCR and PER. Our present results strongly corroborates with those of researches which reported that Nile tilapia (*Oreochromis niloticus*) fry, fingerling were strongly suppressed by feeding with 100% BSFL (Rana et al., 2015; Muin et al., 2017; Teye-Gaga, 2017; Devic et al., 2018). Total replacement of fishmeal with insect meals has usually been unsuccessful and performed poor, probably because of the dietary imbalances and deficiencies (Henry et al., 2015). Incorporating BSFL meal in fish diets is possible but limited by low nutritive value (Kroeckel et al., 2012). Lock et al. (2016) indicated that replacing fishmeal with 100% BSFL meal increased the level of thiobarbituric acid-reactive substances, which resulted in lower palatability of the diet. Li et al. (2017) indicated that at least 50% of fishmeal could be replaced with BSFL meal in juvenile Jian carp (*Cyprinus carpio*), but dietary stress and intestinal histopathological damage were observed when replacement levels exceeded 75%. Another study by Burr et al. (2012) highlighted that replacing fishmeal with high percentages of BSFL meal resulted in decreased palatability, which reduced feed intake and nutrient absorption. Kroeckel et al. (2012) observed that increasing levels BSFL meal in diets of juvenile turbot (*Psetta maxima*) reduced palatability, acceptability and FI of fish. Reduced palatability is often noticed in diets in which fishmeal is substantially replaced with alternative protein source, especially if it contains anti-nutritional factors (ANFs) (Kroeckel et al., 2012). Although this study did not determine the types and concentration of ANFs for the various test ingredients such as BSFL meal, it had been widely reported that substantial increase in BSFL meal in fish diet could progressively depress fish growth (Kroeckel et al., 2012; Talamuk, 2016; Xiao et al., 2018; Caimi et al., 2020).

Decreased fish growth performance and feed utilisation with a corresponding increase in the dietary insect meal inclusion could be due to the substantial increase in chitin content. Chitin is a component of the exoskeleton in invertebrates (Talamuk, 2016), that is relatively resistant to degradation and not easily digested by animals (Shoba et al., 2016) including several fish species because these fish lack chitinase activity (Rust, 2002; Zhou et al., 2018). Insect chitin affects digestibility of nutrients (Belforti et al., 2015). High chitin contents with a corresponding increase in the dietary BSFL meal inclusion levels were postulated to decrease FI, growth and digestibility of juvenile Turbot (*Psetta maxima*) (Kroeckel et al., 2012), Yellow catfish (*Pelteobagrus fulvidraco* (Xiao et al., 2018), Jian carp (*Cyprinus carpio* var Jian) (Zhou et al., 2018). and Thai climbing perch (*Anabas testudieneus)* (Mapanao et al., 2021).

Condition factor

Condition factor of *C. gariepinus* fingerlings was also not affected by replacing fishmeal with BSFL meal at all levels. Similar results were obtained in Atlantic salmon (Lock et al., 2016), Yellow catfish (*Pelteobagrus fulvidraco* (Xiao et al., 2018), Thai climbing perch (*Anabas testudieneus)* (Mapanao et al., 2021) and Nile tilapia (*Oreochromis niloticus*) (Tippayadara et al., 2021; Limbu et al., 2022) in which the inclusion of BSFL meal up to 100% was used.

Water quality parameters

The water quality parameters (temperature, pH, dissolved oxygen, ammonia and nitrate) values recorded throughout the rearing period was within the recommended optimum range for all the treatments, thus did not have any adverse effect on the growth of catfish fingerlings. These values are similar to those of Talamuk (2016) and Matanda et al. (2017). The suitable water quality parameters recorded in the experimental water tanks could be attributed to good water management practices, such as administering high-quality feed, which might have resulted in high FI and digestibility; avoidance of feed waste by giving just the right amount of diet based on the recommended feeding rate. Also, water levels in the tanks were maintained by constantly topping up, thus replenishing the culture system with freshwater.

Carcass composition

Further in the current study, whole-body proximate composition of fish was affected by the BSFL inclusion as the fish meal replacer in the diets. Decreased protein in carcass composition of *C. gariepinus* fingerlings with a corresponding increase in dietary BSFL meal inclusion was observed. Similar findings were reported in Nile tilapia (*Oreochromis niloticus*) (Teye-Gaga, 2017), Yellow catfish (*Pelteobagrus fulvidraco*) (Xiao et al., 2018), Thai climbing perch (*Anabas testudineus*) (Mapanao et al., 2021). This could relate to excess chitin replacement in BSFL meal, which reduced diet palatability, thereby reducing FI, protein digestibility, nutrient digestibility and absorption (Kroeckel et al., 2012). Reduced FI with decreasing level of fishmeal in the diet of turbot, Nile tilapia and rainbow trout was also observed (Ogunji et al., 2008; Stamer et al., 2014). Though this study did not focus on amino acid composition of the diets, the disparities could also be due to reduced quality of amino acids especially the essential amino acids. Kroeckel et al. (2012) reported that fishmeal contains superior quality of essential amino acids compared to BSFL meal. Increasing inclusion levels of the BSFL meal and decreasing level of fishmeal reduce the quality of dietary protein and may affect digestibility.

With increasing amounts of BSFL meal in diets, whole-body nitrogen free extracts content decreased significantly mainly due to a significant decreased FI and therefore low carbohydrates intake. Kroeckel et al. (2012) reported a decrease in gross energy content with increased amounts of housefly maggots due to decreased FI and therefore low energy intake. Crude fibre content of the whole body composition might have been also affected by dietary treatments. Increasing BSFL meal inclusion level in the diets increased the crude fibre content of the whole body composition due to the substantial increase in chitin content. BSFL has a high fibre content (Mulianda et al., 2020). Some studies reported that BSFL contained chitin at 8.7% dry matter (Diener *et al*., 2009) and 9.6% dry matter (Kroeckel et al., 2012). However, the increase in BSFL meal in the experimental diets might have increased the proportion of chitin per unit of dry matter (Zhu et al., 2016), which was absorbed by the fish.

The whole-body fish ether extracts increased significantly with a corresponding increase in the dietary insect meal inclusion. This finding also agrees with those of Rana et al. (2015), Muin et al. (2017), Teye-Gaga (2017) and Devic et al. (2018), who reported an increase in body crude fat content and saturated fatty acid content in Nile tilapia (*Oreochromis niloticus)* fry, fingerlings. Our results are also in line with those of Mapanao et al. (2021), who observed an increase in crude lipids of Thai climbing perch (*Anabas testudineus*) that were fed diets containing BSFL meal up to 100%. However, other studies found that in rainbow trout, the crude lipid content of the whole body and muscle tissue decreased significantly as the amount of BSFL increased (Sealey et al., 2011; Kroeckel et al., 2012). These researches suggested that the defatting process influences the level of the lipids and that this may have reduced the lipid bioavailability (Kroeckel et al., 2012). The experimental diets also affected ash content of the fish carcasses. Insect exoskeletons are notably rich in mineral salts (Hu et al., 2017), so replacing fishmeal with BSFL could have substantially change the mineral content of the diets and affect the ash content of fish carcass.

Conclusion

BSFL meal protein could be used to partially replace fishmeal protein in the diet of African catfish (*C. gariepinus*). Replacement at 25% BSFL meal improved growth performance and feed utilisation. However, replacing fishmeal protein with BSFL meal protein in African catfish fingerling diets decreased concentration of crude protein, ash, nitrogen free extracts, and increased ether extracts and fibre contents of the whole body fish composition.

CONFLICT OF INTRESTS

The authors have not declared any conflict of interest.

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