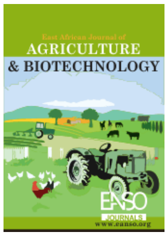

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Original Article

Growth and Economic Performance of African Catfish (*Clarias gariepinus* Burchell, 1822) Fed Diets Containing Black Soldier Fly Larvae (*Hermetia illucens* Linnaeus, 1758)

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Fishmeal, Black Soldier Fly Larvae Meal, Hermetia illucens, African Catfish, Clarias gariepinus, Growth performance, Economic performance.

ABSTRACT

Insect meals have been proposed as a potential alternative protein source for replacing fishmeal (FM), the key ingredient in aquaculture diets, yet is the most scarce and expensive. However, not much work has been done on the effects of replacing FM with black soldier fly (*Hermetia illucens*) larvae meal (BSFLM) on the growth and economic performance of African catfish (*Clarias gariepinus*) fingerlings. This study investigated the effect of replacing FM with BSFLM on the growth and economic performance of African catfish. Five isonitrogenous (40% CP) diets were formulated to replace 100% FM, 75% FM, 50% FM, 25% FM and 0% FM with BSFLM, hereafter referred to as $BSFLM_0$, $BSFLM_{25}$, $BSFLM_{50}$, $BSFLM_{75}$ and $BSFLM_{100}$ diets, respectively. Six hundred mixed-sex fingerlings of mean weight 0.46±0.02g were stocked in 15 plastic tanks (40 fingerlings/tank, three replicates/treatment). Fish were hand-fed at 6% body weight twice a day for 12 weeks. Significant differences ($P<0.05$) were found in final body weight, body weight gain, specific growth rate, feed conversion ratio, and condition factor. The best growth performance was recorded in fish fed on $BSFLM_{25}$. The economic analysis indicated that BSFLM diets reduced significantly ($P<0.05$) the incidence cost compared to the ($BSFLM_0$). $BSFLM_0$ had the highest incidence cost (KES 99.99), while $BSFLM_{100}$ (KES 59.93) yielded the lowest. BSFLM diets significantly increased ($P<0.05$) the profit index compared to $BSFLM_0$. $BSFLM_{100}$ and $BSFLM_{25}$ had the highest profit indexes (KES 5.06) and (KES 4.28) respectively. Additionally, the best harvest weight and value of fish were found to be higher in $BSFLM_{25}$ compared to other compositions, even when the amounts fed and feed cost per kg were not significantly different from $BSFLM_0$. The study demonstrated that BSFLM is a cost-effective alternative to FM in diets of African catfish and hence can replace BSFLM up to 25% without negative effects on growth and economic benefits.

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INTRODUCTION

Aquaculture production is one of the agricultural sectors that is playing a crucial role in improving the nutrition and food security of people globally and has further revealed the potential to meet future food demand, particularly the need for protein (FAO, 2020). Fishmeal has long been considered the primary source of protein in the production of aquafeeds (Xiao et al., 2018) because of its unique nutritional properties: high-quality protein, well-balanced amino acid profile, high essential fatty acids, and minerals close to the requirement levels needed by most of the farmed aquatic organisms (Shati et al., 2022). However, aquaculture production has been threatened by the over-reliance on fishmeal (Chang et al., 2016), which is the key ingredient used in the formulation of fish and other livestock feeds (Kirimi, 2019)

The competition between the livestock feed industry and the human population for fish to produce fishmeal has resulted in a steady decline in capture fisheries, thereby exacerbating the high costs of fishmeal (De Roos et al., 2017). Due to the high cost of fishmeal, which makes commercial production of fish highly capital intensive, accounting for more than 50% of the total variable operating costs (Limbu et al., 2022), there is an urgent need to explore cheap alternative protein feed sources (Shati et al., 2022).

Nonetheless, studies have demonstrated that insects represent a valid substitute for the global problems associated with the expensive, unsustainable protein sources for fish feed (Huis et al., 2013). Among insect species, the black soldier fly (*Hermetia illucens*) is considered one of the most promising protein source substitutes due to its wide distribution in both tropical and subtropical climate zones (Zurbrügg et al., 2018). Black soldier fly larvae meal has become the key ingredient used in fish feeds following technological innovation in feed production and high incentives for seeking high-quality and affordable alternatives for fish meal and fish oil (Xiao et al., 2018). It is also easy to culture due to the capability to convert various forms of organic wastes into biomass of high-quality proteins, essential amino acids (EAA), fat, vitamins, and minerals (Gasco et al., 2019). The black soldier fly (BSF) also reproduces easily, has a high growth rate, can control bacteria, favouring

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low risk of zoonotic disease transmission and in addition, has a prebiotic effect on the fish (Gariglio et al., 2019).

The nutritive value of BSFLM in aquaculture feeds has been tested with success to replace fishmeal on several fish species, including Nile tilapia (*Oreochromis niloticus*) (Tippayadara et al., 2021; Shati et al., 2022; Limbu et al., 2022); Rainbow trout (*Oncorhynchus mykiss*) (Terova et al., 2019), Jian carp (*Cyprinus carpio var. Jian*) (Zhou et al., 2018) and Pacific white shrimp (*Litopenaeus vannamei*) (Cummins et al., 2016). However, most of the studies have focused on fishmeal protein replacement with black soldier fly larvae meal (BSFLM). Thus, there is a scarcity of information on the effects of replacing fishmeal with BSFLM in the diets of African catfish. In addition, most of the studies are focused on the growth performance and carcass composition of the fish-fed BSFLM at different inclusion levels, but there is a paucity of information on the economic performance of using BSFLM in African catfish production. This study, therefore, evaluated the utilisation of black soldier fly larvae (*H. illucens*) meal as a fish meal replacement in the diets of African catfish (*Clarias gariepinus*) fingerlings in terms of growth and economic performance.

MATERIAL AND METHODS

Study Area and Diet Preparation

The experiment was conducted from 18/03/2022 to 10/06/2022 at Jaramogi Oginga Odinga University of Science and Technology, Fish Farm 0°05’38.0” S, 34°15’31.0” E (Latitude: -0.093889; Longitude: 34.258611), Siaya County, Kenya. The cultured BSFL was processed at the university’s Insect Farm. Other feed ingredients (Table 1) were purchased from the local Agrovet outlets and ground separately into finer particles using a semi-commercial stainless steel feed mixer Model M20A KITMA China, at 100 rpm operated at 220-240 Volts. A proximate analysis of test ingredients was conducted to guide the formulation of five isonitrogenous (40 % crude protein) experimental diets. The diets were prepared by replacing fishmeal with BSFLM at 0% ($BSFLM_0$) (Control), 25% ($BSFLM_{25}$), 50% ($BSFLM_{50}$), 75% ($BSFLM_{75}$) and 100% ($BSFLM_{100}$). During the production of diets ($BSFLM_0$, $BSFLM_{25}$, $BSFLM_{50}$, $BSFLM_{75}$ and $BSFLM_{100}$), all the ingredients were thoroughly mixed with 25% clean water to make the homogenous dough and pelletised using a 2 mm diet commercial pelletising machine. The pellets were sundried, packed and stored in a clean, dry, and cool environment. The pellets were finally crushed to approximately 0.5 mm to facilitate ingestion by the fingerlings.

Proximate Analysis of the Experimental Diets

Samples of experimental diets were subjected to proximate analysis in triplicates to determine the crude protein, dry matter content, ether extracts, crude fibre, ash, and nitrogen-free extracts. The chemical compositions of the formulated diets were determined following the Association of Official Analytical Chemists [AOAC] (1998) procedures. Dry matter content was determined by drying in an oven at 105 °C for 8 hours. Crude lipid content was determined by Soxhlet extraction with petroleum ether. Ash content was determined by incineration in a muffle furnace at 550 °C for 8 hours. Crude protein was determined by measuring nitrogen (N × 6.25) using the Kjeldahl method. The crude fibre was determined by digesting dried lipid-free residue with 1.25% Sulphuric acid, 1.25% Sodium hydroxide and calcined. The nitrogen-free extracts) were determined as 100 – (moisture content + crude protein + crude fat + ash + fibre). The feed composition and resulting proximate analysis are shown in *Table 1*.

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Table 1: Ingredients and proximate composition of the experimental diets

		$BSFLM_0$	**$BSFLM_{25}$**	**$BSFLM_{50}$**	**$BSFLM_{75}$**	**$BSFLM_{100}$**
Ingredient inclusion (g kg^{-1})	BSFL meal	0	20.15	40.3	60.45	80.6
	Fishmeal	50.44	37.83	25.22	12.61	0
	Cassava	28.84	24.26	19.69	15.12	10.55
	Rice bran	18.72	15.76	12.79	9.82	6.85
	Vitamin-mineral premix	2	2	2	2	2
Proximate composition (%)	Crude protein	39.72±0.39	40.34±0.34	40.17±0.14	39.75±0.07	40.39±0.35
	Dry matter	91.68±0.07	91.73±0.09	92.13±0.10	92.24±0.14	92.61±0.08
	Crude fibre	6.32±0.10	6.98±0.02	7.30±0.08	8.33 ± 0.03	8.31±0.09
	Ash	15.30±0.03	16.16±0.10	14.21±0.06	13.40±0.04	12.27±0.06
	Ether extracts	8.36±0.42	8.15±0.44	8.39±0.67	8.26±0.22	8.37±0.19
	Nitrogen free extracts (NFE)	30.31±0.67	28.37±0.65	29.94±0.78	30.26±0.22	30.67±0.40

**Black soldier fly treatments – BSFLM0 (0%); BSFLM25 (25%); BSFLM50 (50%); BSFLM75 (75%); BSFLM100 (100%)*

Experimental Design

A total of six hundred mixed-sex African catfish (*C. gariepinus*) fingerlings of 0.46±0.02g mean weight were sourced from Tigoi Fish Farm located in Vihiga County, Western Kenya and acclimatised for fourteen days prior to the experiment. The experimental fish were randomly stocked in 15 circular plastic drums at a density of 40 fish per tank. Each plastic tank had a capacity to hold water at a volume of 250 L. The fish were randomly assigned to the five experimental diets containing BSFLM in varying proportions of 0% ($BSFLM_0$), 25% ($BSFLM_{25}$), 50% ($BSFLM_{50}$), 75% ($BSFLM_{75}$) and 100 % ($BSFLM_{100}$) in triplicates. The experimental fish were hand-fed twice a day (1000 hours and 1600 hours) at 6 % of body weight for 84 days, and the amount of fish feed was adjusted according to the fish's body weight every two weeks.

Sampling

Fish sampling was done every 14 days. The individual length (cm) and weight (g) of the fish were determined using a measuring board and an electronic weighing scale (Scout Pro Balance, Ohaus), respectively. To evaluate the growth and feed efficiency, the following standard formulas were used:

$$\text{Specific growth rate (SGR, \%)} = \frac{\text{Ln Body weight final} - \text{Ln Body weight initial}}{\text{Days of experiment}} \text{ x } 100 \quad (1)$$

$$\text{Body weight gain (BWG, g)} = \text{Final weight} - \text{Initial weight} \quad (2)$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Feed provided (g)}}{\text{Live weight gain (g)}} \quad (3)$$

Length-Weight Relationship (LWR)

The total length (cm) of fish was determined using a measuring board, whereas fish weight was determined by the Scout Pro Balance, Ohaus. The equation below was used to estimate the LWR:

$$W = aL^b \quad (4)$$

Where W = Fish weight (g); L = Total fish length (cm); a = Exponent describing the rate of change of weight with length (= the intercept of the regression line on the Y axis) and b = Regression line slope

The equation was log-transformed for estimating the parameters ‘a’ and ‘b’. When b = 3, an isometric pattern of growth occurs, but when b is not equal to 3, the allometric pattern of growth occurs, which may be positive if >3 or negative <3. The log-transformed data gave a regression equation:

$$\text{Log } w = \log a + b \log L \quad (5)$$

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Where a = Constant and b = The regression coefficient

$$\text{Relative condition factor } (K_n) = \frac{W_o}{a \times L^b} = \frac{W_o}{W_p} \quad (6)$$

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

Water Quality Management

Water quality was considered throughout the trial, and water in each experimental unit was maintained to be within the critical limits acceptable for the growth and health of catfish fingerlings. Temperature, pH, and dissolved oxygen (DO) were monitored on a daily basis using a multi-parameter water quality meter (YSI 550A). Ammonia and nitrite were also measured using chemicals once a fortnight. The mean values of water quality parameters of the circular plastic tanks were stable with minimal variations during the experiment period. The mean values were as follows: Temperature (28.66±0.10°C), pH (7.48±0.02), dissolved oxygen (DO) (3.27±0.08 mg L^{-1}), ammonium (0.41±0.07 mg L^{-1}) and nitrite (0.02±0.01 mg L^{-1}). All the parameters were within the recommended levels for African catfish.

Enterprise Budget Analysis

The partial enterprise budget was conducted to assess the cost-effectiveness and feasibility of using black soldier fly larvae meal (BSFLM) as a replacement for fishmeal in African catfish (*C. gariepinus*) diets. Only the cost of feed was used in the calculation with the assumption that all other operating costs remained constant and thus were not considered. The cost of the feeds ($BSFLM_0$, $BSFLM_{25}$, $BSFLM_{50}$, $BSFLM_{75}$ and $BSFLM_{100}$) were calculated using the prevailing market prices, which were recorded when the feed ingredients were purchased, as shown in Table 2. The value of the fish was calculated using the sale price of KES 300.00.kg^{-1} fish. Further, to gauge the profitability of the alternative, the incident of cost and profit index were calculated using the following formulas.

$$\text{Incident of cost} = \frac{\text{Cost of feed (KES)}}{\text{Weight of fish produced (kg)}} \quad (7)$$

$$\text{Profit index} = \frac{\text{Value of fish produced (KES)}}{\text{Cost of feeding (KES)}} \quad (8)$$

Table 2: Cost of feed ingredients (KES) used in formulating experimental diets

Feed ingredient	Price per Kilogram (KES)
Fish meal (*Rastrineobola argentae*)	250.00
Black soldier fly larvae	150.00
Cassava meal	30.00
Rice bran	20.00
Vitamin-mineral premix	250.00

(**Source**: Author 2022)

Data Analysis

All analyses were conducted using Min tab version 17.0 and Statgraphics Ver 16. Mean comparisons for water quality traits, initial length, final length, initial body weight, final body weight and economic performance parameters were done by the analysis of variance (one-way ANOVA) followed by Tukey HSD post hoc test at $\alpha = 0.05$ to determine the pairwise differences among the diets. Significant differences were considered at $P<0.05$. Indices (body weight gain, specific growth rate and feed conversion ratio) were not subjected to any statistical analysis because they did not meet the parametric analysis requirements since they had

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single values/outputs. The Kruskal-Wallis test was employed to separate the medians and average ranks of condition factors.

RESULTS

Growth Performance and Nutrient utilisation

The BSFLM replacement level had a significant effect on the growth of the fish (P<0.05). $BSFLM_{25}$ recorded the highest final length and final body weight, followed by $BSFLM_{0}$, $BSFLM_{50}$, $BSFLM_{75}$ and finally $BSFLM_{100}$ (*Table 3*). Fish body weight increased by 97% in fish fed on $BSFLM_{0}$ and $BSFLM_{25}$, while an increase of 95%, 94% and 92% was observed in fish fed on $BSFLM_{50}$, $BSFLM_{75}$ and $BSFLM_{100,}$ respectively. Fish fed on $BSFLM_{25}$ performed better than other treatments in terms of body weight gain and specific growth rate. The feed conversion ratios of fish that were fed $BSFLM_{100}$ and $BSFLM_{25}$ were better than other treatments. All the diets recorded a positive correlation coefficient (R^2). The values of condition factor recorded for all the fish ranged between 0.9466 and 1.0049 with $BSFLM_{25}$ having the highest condition factor.

Economic Analysis

$BSFLM_{0}$ had the highest (P<0.05) feed cost per kilogram (KES 139.75) among all the treatments (*Table 4*). The total feed cost was also significantly higher in $BSFLM_{0}$ (KES 43.18) (P<0.05), and it reduced with a corresponding increase in BSFLM inclusion in the diets. Harvested weight and value of harvested fish increased (P<0.05) with fish meal substitution levels from 0 to 25% but dropped drastically from 50 to 100% fish meal substitution diet. Feeding the African catfish fingerlings with BSFLM-based diets reduced significantly (P<0.05) the incidence cost compared to those fed on $BSFLM_{0}$. $BSFLM_{0}$ had the highest incidence cost (KES 99.99), while $BSFLM_{100}$ (KES 59.93) had the lowest incident cost. However, $BSFLM_{25}$ (KES 70.23), $BSFLM_{50}$ (KES 83.61) and $BSFLM_{75}$ (KES 72.56) were not significantly different (P>0.05). On the contrary, the African catfish fingerlings fed on BSFLM-based diets increased significantly (P<0.05) the profit index compared to those fed on $BSFLM_{0}$. $BSFLM_{100}$ and 25% had the highest profit index of (KES 5.06) and (KES 4.28), respectively, while $BSFL_{0}$ had the lowest profit index (KES 3.00).

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Table 3: Growth performance parameters of *C. gariepinus* fed on diets with different levels of black soldier fly larvae meal

PARAMETER	$BSFLM_0$	$BSFLM_{25}$	$BSFLM_{50}$	$BSFLM_{75}$	$BSFLM_{100}$
Initial length (IL) (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]
Final length (FL) (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]
Initial body weight (IBW) (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]
Final body weight (FBW) (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]
Body weight gain (BWG) (g)	11.48	13.87	9.66	7.54	5.80
Specific growth rate (SGR) (% day $^{-1}$)	4.00	4.00	3.64	3.42	3.08
Feed conversion ratio (FCR)	0.83	0.78	0.87	0.81	0.72
Length-weight relationship (R^2)	0.9827	0.9861	0.9826	0.9706	0.8992
Condition factor (K_n)	1.0017 (540.7)	1.0049 (575.9)	0.9962 (540.9)	0.9942 (532.1)	0.9466 (437.9)

**Mean within the same row with different superscript letters are significantly different at P<0.05, n=40*

Table 4: Economic analysis of the African catfish fingerlings fed black soldier fly larvae-based diets

	EXPERIMENTAL DIETS					
PARAMETER	$BSFLM_0$	$BSFLM_{25}$	$BSFLM_{50}$	$BSFLM_{75}$	$BSFLM_{100}$	P-Value
Feed cost/Kg (KES)	139.75±0.53[a]	137.08±1.15[ab]	134.41±1.15[bc]	131.74±1.17[cd]	129.07±1.14[d]	<0.0001
Feed fed (Kg)	0.31±0.01[a]	0.28±0.02[a]	0.23±0.01[b]	0.16±0.01[c]	0.10±0.00[d]	<0.0001
Total feed cost (KES)	43.18±1.17[a]	38.66±1.15[b]	30.51±1.16[c]	20.68±1.16[d]	13.42±1.14[e]	<0.0001
Harvest weight/ Kg	0.43±0.01[b]	0.52±0.01[a]	0.37±0.00[c]	0.28±0.00[d]	0.22±0.00[e]	<0.0001
Value of fish (KES)	129.60±3.15[b]	156.63±3.80[a]	109.51±0.34[c]	85.49±0.87[d]	67.09±0.94[e]	<0.0001
Incident cost (KES)	99.99±2.19[a]	70.23±1.70[bc]	83.61±3.45[b]	72.56±3.79[bc]	59.93±4.46[c]	<0.0001
Profit index (KES)	3.00±0.07[c]	4.28±0.11[ab]	3.60±0.15[bc]	4.16±0.22[ab]	5.06±0.39[a]	0.001

**Mean values with different superscripts in the same row are statistically different from each other (P<0.05)*

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DISCUSSION

Growth Performance and Nutrient utilisation

The present study was conducted to evaluate the effect of replacing fishmeal (FM) with black soldier fly larvae meal (BSFLM) on the growth performance, feed utilisation and economic performance of African catfish (*Clarias gariepinus*). All the diets registered a gradual increase in the mean weight. This can be attributed to the similarity in the initial crude protein and fat content of the experimental diets coupled with the well-balanced and formulated diets. Fish-fed $BSFLM_{25}$ registered the best results than all other experimental diets. Similar findings have been reported in yellow catfish (*Pelteobagrus fulvidraco*) by Xiao et al. (2018) but contrary to Limbu et al. (2022) in Nile tilapia that registered high growth performance and feed utilisation in fish that were fed diets supplemented with BSFLM 75%. The increased growth performance of the fingerlings fed on the $BSFLM_{25}$ diet was due to increased feed efficiency. In this study, the fingerlings fed on the $BSFLM_{25}$ diet had lower figures for FCR, indicating efficient utilisation of nutrients contained in the diet.

Fish body weight increased by 97% in fish fed on $BSFLM_{0}$ and $BSFLM_{25}$, while an increase of 95%, 94% and 92% was observed in fish fed on $BSFLM_{50}$, $BSFLM_{75}$ and $BSFLM_{100,}$ respectively. Previous studies on African catfish have reported similar results to this study; for instance, a higher body weight gain of 97% was observed in fish that were fed diets containing 30% BSFLM (Talamuk, 2016). A decrease in body weight gain (BWG) and specific growth rate (SGR) was also observed in fish that were fed diets containing BSFLM 50%, 75% and 100%, respectively. Similar results indicated that Nile tilapia (*Oreochromis niloticus*) fry fingerling was strongly suppressed by feeding with 100% BSFLM (Rana et al., 2015; Muin et al., 2017; Teye-Gaga, 2017 and Devic et al., 2018) but contrary to Limbu et al (2022) who recorded the highest body weight gain in fish that were fed diets containing 75% BSFLM. The decrease in body weight gain observed in the present and previous trials may have been mainly associated with the dietary imbalances and deficiencies found in BSFLM (Kroeckel et al., 2012; Henry et al., 2015). Previous studies have also reported reduced feeding and growth as a result of higher levels of dietary BSFLM and recommended different optimal inclusion levels of 25% (Xiao et al., 2018) in Nile tilapia. Other studies indicated that fish replacement with high inclusion levels of BSFLM decreased the palatability of the BSFL-based diets, which lowered the feed consumption and absorption of nutrients (Burr et al., 2012).

A reduction in palatability of the feed is usually noticed in feeds in which fishmeal is substantially replaced with other protein sources, especially if they contain anti-nutritional factors (ANFs) (Kroeckel et al., 2012). Even though the present trial did not focus on the types and concentrations of ANFs for the ingredients that were used, BSFLM has been reported to have a growth-inhibitory effect, which has been linked to anti-nutritional factors (Talamuk, 2016) that lower palatability and nutrient digestibility. Black soldier fly larvae contain chitin, which is an exoskeleton component in invertebrates (Talamuk, 2016) and is relatively difficult to degrade by fish (Zhou et al., 2018). The diminishing growth performance and feed utilisation with a corresponding increase in the dietary inclusion level of BSFLM could be due to the substantial increase in chitin content. High levels of chitin content with a corresponding increase in the dietary BSFLM inclusion levels were postulated to have reduced the feed consumption and digestibility as well as the growth performance of Yellow catfish (*Pelteobagrus fulvidraco* (Xiao et al., 2018) and Jian carp (*Cyprinus carpio* var Jian) (Zhou et al., 2018).

Fish fed on $BSFLM_{25}$ registered the lowest FCR compared with other diets. The FCR values in the present study were lower than those reported by Talamuk (2016) when BSFLM was included in the diets of African catfish. A lower FCR serves as an indicator of better feed utilisation (Devic et al., 2018). The low FCR in fish fed on $BSFLM_{25}$ was in line with Xiao et al.(2018) findings in

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yellow catfish (*Pelteobagrus fulvidraco*) when conventional protein sources were replaced at 100% with BSFLM. FCR in fish-fed $BSFLM_{25}$ may have been a factor in the inclusion level of BSFLM in the diet. Observations by Kroeckel et al. (2012) indicated that high inclusion levels of insect meals decreased digestibility and utilisation of nutrients because of chitin contained in BSFLM.

Length-Weight Relationship (LWR)

The length-weight relationship of the current study indicated isometric growths in all fish fed on the experimental diets that entailed an increase in weight for every unit increase in length (Daliri, 2012). This suggests good physiological logical conditions of fish in relation to its welfare associated with optimal physio-chemical and biological qualities of water in fish ponds.

Relative Condition Factor (K_n)

The relative condition factor (K_n) values of African catfish fingerlings across all the treatments range from 0.9 to 1.0; hence, the condition factors of *C. gariepinus* fingerlings were not affected by replacing fishmeal with BSFLM at all levels. According to Anani and Nunoo (2016), the condition factor greater than 1.0 implies the good health condition of fish. These condition factor values, which are high, could be due to good water quality parameters maintained throughout the experiment and the high nutritional quality of the feeds. 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 (*O. niloticus*) (Tippayadara et al., 2021; Limbu et al., 2022), in which the inclusion of BSFLM up to 100% was used.

Economic Analysis

Feed constitutes a major expense in aquaculture production; hence, profitability and sustainability are factors of cost minimisation. In the present study, the black soldier fly larvae meal has been used as a substitute for fish meal and resulted in varying economic performances in terms of incidence costs and profit index. The costs of producing a kilogram of feed in the present study were highest in diets containing $BSFLM_{0,}$ which translated into higher incidence costs. This was attributed to the higher cost of fishmeal (KES 250.00) (*Table 2*). On the other hand, $BSFLM_{100}$ had the lowest production costs attributed to the low market price of black soldier fly larvae (KES 150.00), as it formed the bulk of protein in the $BSFLM_{100}$-based diet. The economic analysis also indicated positive net returns for all the diets. The difference in economic performance for the experimental diets in the present study was due to varying major protein sources with different prices. The economics of feed production indicated that the costs of the diets were minimised by replacing fishmeal with BSFLM, hence contributing to its cost-effectiveness. Similar results have been reported by Abdel-Tawwab et al. (2020) in European sea bass (*Dicentrarchus labrax*), Wachira et al. (2021) in Nile tilapia and Rawski et al. (2021) in Siberian sturgeon, when conventional sources of proteins were replaced with BSFLM.

$BSFLM_{75}$ and $BSFLM_{100}$ diets recorded the highest profit index, though they had lower final weight gain. This was contributed by the relatively low market price of black soldier fly larvae (KES 150.00). To increase fish farm profits, the cost of feed must be reduced, and considerable effort must be focused on finding alternatives to fishmeal from either plant, animal or insect protein sources (Limbu et al., 2022). However, the production of fish using diets compounded with alternative protein sources apart from fish meals will take longer for fish to reach market size. This was evidenced by Ogunji et al. (2008) and Kirimi et al. (2016), who reported that in relation to the culture period, when alternative protein sources are used in tilapia feeds, the rate of fish growth was reduced, leading to increased rearing time. The low cost of the protein sources would reduce the entire cost of raising the fish, compensating for the delayed growth and time lost, consequently increasing profitability. However, this might not be entirely

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good for intensive commercial farmers who are looking for high profits in the shortest possible time, but immensely benefits small to medium-scale semi-intensive farmers.

CONCLUSION

This study demonstrated that fish fed on $BSFLM_{25}$ exhibited better growth performance in terms of body weight gain, specific growth rate and feed conversion ratio compared to other experimental diets. The study also confirms that the total costs, harvest weight and value of fish were found to be higher for the $BSFLM_{25}$ replacement as compared to all the other experimental diets, even when the amounts fed and the feed cost per kg were not significantly different from the wholly fishmeal-based diet. The profit indices were better for all BSFLM-based diets as compared to whole fishmeal-based diets. Therefore, BSFL meal protein can be used to replace up to 25% of FM protein in the African catfish diet without any negative effects on the growth and feed conversion rate and improve the profitability of the fish.

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Competing Interests

The authors declare that they have no competing interests.

Ethical Approval

The experiment was conducted following the approved procedures and guidelines from the Ethics Committee of Jaramogi Oginga Odinga University of Science and Technology (JOOUST) with approval number ERC 29/4/22-23. A research permit was granted by the National Commission for Science, Technology, and Innovation (NACOSTI) with the license number NACOSTI/P22/17210.

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