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Partial Replacement of Fishmeal with Black Soldier Fly Larvae Meal in Nile Tilapia Diets Improves Performance and Profitability in Earthen Pond

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A B S T R A C T

Insect meals have the potential to be used as a source of nutrients in aquafeeds due to their high nutritional profile and cost effectiveness. The objective of this study was to elucidate the impact of black soldier fly larvae meal (BSFLM) as a replacement for fish meal (FM) on Nile tilapia (*Oreochromis niloticus,* L) growth performance, survival rate, somatic indexes and economic benefits. Four experimental diets were prepared; three with BSFLM as a substitute for FM at 25 % (T25 %), 50 % (T50 %) and 75 % (T75 %) and a control diet without BSFLM (T0 %, 100 % FM). A total of 360 fingerlings weighing about 20 - 30 gs each were assigned to twelve cages built in a 720m^2 earthen pond, with 30 fingerlings in each cage in a completely randomized design with three replications in each treatment group. The fingerlings were fed the experimental diets for 26 weeks. The results showed that the treatment diets did not significantly affect body weight gain and daily feed intake ($p > 0.05$). However, treatment T50 % (52.16 g) had the highest body weight gain while treatment T75 % (46.00 g) had the lowest body weight gain even though not statistically different ($p > 0.05$). The body length also followed the same trend being higher in T50 % (16.50 cm) and lowest in T75 % (15.91 cm). The survival rate was significantly influenced ($p < 0.05$) by the diet treatment groups, while blood parameters, visceral somatic and hepatosomatic indexes did not vary significantly ($p > 0.05$) across the treatment diets. Return on investment and the cost-benefit ratio were significantly ($p < 0.05$) affected by the partial replacement of FM with BSFLM. Diets T25 %, T50 % and T75 % had higher ($p < 0.05$) profit margins when compared with diet T0 % (control). The study found that BSFLM can replace FM in diets for Nile tilapia without compromising on the growth performance of the fish while also increasing the profitability.

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Introduction

In recent years, the global aquaculture output has risen tremendously and is responsible for contributing to approximately half of the total food fish consumed by humans [1]. The sector is critical in meeting the future demand for food especially dietary protein, fatty acids and micronutrients in low income countries [2]. In addition, the expansion of aquaculture has significantly aided economic growth and agricultural development in many developing countries [3,4]. According to Food and Agriculture Organization estimates, agricultural output from fisheries and aquaculture must increase by more than 60 % to feed the world population by 2050 [5]. Based on a study by Munguti et al. [6], Africa has a large potential for fish farming, with 43 % of its surface area suitable for commercial fish production. The world's consumption of fish is at an average of 20.5 kg per capita annually [1] while the consumption in Kenya is very low at 5 kg annually [7]. The production of aquafeeds should be accelerated in order to meet the projected demand for fish [8]. However, the aquaculture sector is hampered by the challenge of fish feeds which makes up to 70 % of costs of fish production [9]. Fish meal and soybean meal have been the main sources of protein in formulation and production of aquafeeds [10].

Fish meal (FM) has been the primary protein ingredient in aquafeeds because of its high protein content, balanced essential amino acids, high digestibility and good palatability, which are important for nutrient utilization in animals [11,12]. This makes it a suitable source of nutrients of nearly all cultured fish species. Overdependence on FM as a source of nutrients for fishes (and other aquatic organisms) has subjected it to tremendous pressure which has led to its overexploitation making it unsustainable in supporting the expanding aquaculture production [13]. This is besides the existing competition between the aquatic organisms on one side and the human beings and livestock for the FM. This has been identified as a food security concern [14]. This implies that FM faces both economic and ecological problems hence leading to decline in aquaculture production triggering a search for alternative options [15]. To increase aquaculture output, fish feeds must be standardized with less expensive, readily available, and safe raw materials derived primarily from plant and animal protein sources and produced sustainably. Replacement of FM with plant-based materials in fish diets is not a suitable option due to imbalance of amino acids, high fiber content, the presence of non-starch polysaccharide and presence of anti-nutritional factors [16] therefore, their utilization is limited. It is of urgent need to explore other alternative sources of protein for sustainable aquaculture feeds production [17].

The potential role of insects to act as both food and feed has previously been highlighted by FAO [18]. According to van Huis [19], some insect species can provide sustainable proteinaceous feed by efficiently utilizing organic wastes thus providing alternatives. Insect meal has been adopted in animal feeding due to its high nutritional composition in terms of amino acids, vitamins, lipids and minerals when compared to other protein sources such as FM and soybean meal [20]. Moreover, insect meal has been established as a good source of essential amino acids like methionine, leucine, and lysine with no anti-nutritional elements [21]. Black solder fly larvae (*Hermetia illucens* L) (BSFL) has been considered and even used as an alternative protein source in various animal feeds [21]. The BSFL, like fish meal, contain approximately 30 % - 58 % protein, 10 % - 30 % lipids, and has an excellent essential amino acids profile [22], as well as macro and micro-minerals and vital vitamins [23] thus offering available cheap protein source for aquatic animals [24]. Various studies have been carried out to determine the effect of using and/or replacing the conventional protein sources (mainly fish and soya meals) with BSFL meal on production performance of different fish species such as the Nile tilapia (*Oreochromis niloticus*) [25, 26]; Rainbow trout (*Oncorhynchus mykiss*) [27] and Jian carp (*Cyprinus carpio* var. Jian) [28] with none of them reporting negative impacts. Tilapia fish are among the most important warm-water fish cultured worldwide, accounting for approximately 7 million tons of total production [14]. Likewise, Nile tilapia is the most commercially preferred freshwater fish among farmers and consumers in Kenya [6]. There are concerted efforts to support the species for increased productivity and profitability, however, the quality and high cost of feeds is a major constraint that requires immediate attention. The feed has to be of high quality and affordable to smallholder fish producers. Thus, the goal of this study was to evaluate the dietary impact of BSFL meal as a partial replacement for fishmeal on Nile tilapia growth performance, survival rate, somatic indexes, hematology, and economic benefits in Kenya.

Materials and methods

Description of the study area

The experiment was conducted at the National Aquaculture Research Development and Training center (NARDTC) located in Sagana, Kirinyaga County of Kenya. Sagana is located between 0° 39′S latitude and 37° 12′E longitude. It is situated at an altitude of 1230 m above sea level.

Experimental diets

Four experimental fish diets were formulated to be isonitrogenous and isocalorific as shown in Table 1. The ingredients used to formulate the diets were purchased from local farm input suppliers. The black soldier fly larvae (BSFL) was obtained from International

Table 1
Formulation of the experimental diets.

Ingredient	T0 %	T25 %	T50 %	T75 %
Pollard	7.00	7.00	7.00	7.00
Rice Polish	20.00	19.25	19.00	18.75
Maize germ	22.00	22.00	21.50	21.00
Fish meal	7.00	5.25	3.50	1.75
BSFLM	0	2.50	5.00	7.50
Soybean Meal	35.00	35.00	35.00	35.00
Sunflower Cake	5.00	5.00	5.00	5.00
Lysine	1.00	1.00	1.00	1.00
Methionine	1.00	1.00	1.00	1.00
Fish Premix[1]	2.00	2.00	2.00	2.00
TOTAL	**100.00**	**100.00**	**100.00**	**100.00**
Estimated nutrient composition				
CP (% DM)	30.60	30.52	30.42	30.32
Energy (Kcal/kg DM)	3037.21	3049.11	3049.95	3050.80

*T0- Diet 1- control (without black soldier fly larvae meal inclusion), T25-Diet 2 (25 % substitution rate), T50-Diet 3 (50 % substitution rate) and T75-Diet 4 (75 % substitution rate, i.e., maximum BSFLM inclusion). [1]Fish premix composition vitamins A, D3, E, B1, B2, B6, K3, C and trace minerals Zinc, Cobalt, Iron, Manganese, Magnesium, Selenium, Calcium, and Phosphorus.

center of Insect Physiology and Ecology (ICIPE) (1°13′15.6″S 36°53′48.2″E) where it was reared on brewer's spent grain. Proximate analysis was carried out on the ingredients and the results used to formulate the treatment diets. The control diet (T0 %) was devoid of BSFL meal and represented the standard against which the other experimental diets were compared. The experimental diets were formulated to meet the nutritional requirements for Nile tilapia [22]. Due to the differences in the nutritional composition of FM and BSFLM, substitution of FM by BSFLM was carried out while ensuring the other dietary ingredients in the fish diets were adequate and almost similar across the treatments. Diets T0 % (control) T25 %, T50 % and T75 % were prepared with BSFLM replacement levels of 0 %, 25 %, 50 % and 75 % of FM respectively. The feedstuff ingredients were ground separately and mixed thoroughly to make a homogenous blend. The resultant mash diets were then pelletized into semi-floating pellets using a 2 mm meat-mincing machine. The pellets were properly sundried and stored in gunny bags until used in the experiment. The amount of feed fed to different treatment groups was kept constant and was adjusted every two (2) weeks to match the body weight. It is however noteworthy that feeding was done to satiety.

Experimental fish and experimental design

The study utilized 12 experimental cages with dimensions of 2 $m \times 2.8\ m \times 1$ m, which were set up in an earthen pond measuring 18 m x 40 m. The pond was limed with 250 g/m^2 of Calcium Carbonate ($CaCO_3$) and fertilized with 2 g/m^2 of Dicalcium Phosphate (DAP) per week. A total of 360 mixed sex Nile tilapia fingerlings were sourced from the NARDTC Sagana, Kenya. They were then allocated to the cages at a stocking density of 30 fingerlings per cage using a completely randomized design. The four treatment groups were replicated three times each. The experimental diets prepared to be isonitrogenous were labeled as T0 % (0 % BSFLM), T25 % (25 % BSFLM), T50 % (50 % BSFLM) and T75 % (75 % BSFLM). The fingerlings were acclimatized to the environmental conditions for two (2) weeks while being fed a commercial diet before the feeding trial with the experimental diets started. Their respective initial weights were recorded by weighing the fingerlings together initially. The feeding trial lasted for 26 weeks. Water quality was measured throughout the experimental period to check for any deviations from the normal water conditions for Nile tilapia fish.

Chemical analysis of the experimental diets

The treatment diet samples were analyzed for dry matter (DM), ash, crude protein (CP), crude fiber (CF), crude lipids and energy using proximate analysis protocol given by association of official analytical chemists [29]. Dry matter was calculated after the weight loss due to the 24-h drying process at 105 °C. Ash content was determined by incineration at 600 °C for two hours. Total nitrogen content was determined by Kjeldahl method where crude protein was considered as being equal to nitrogen (N) multiplied by a factor of 6.25. The crude lipid content was determined by diethyl ether extraction. Crude fiber analysis was carried out using fiber cap procedure (acid and base digestion) while energy content was measured using a bomb calorimeter.

Growth performance

Sampling was done after every 14 days by manually removing all the fish from each of the 12 cages into buckets containing pond water and numbered 1 to 12 to correspond with the treatment cages. Data on the fish length and weight were recorded so as to estimate weight and length gain. These parameters were used to determine growth performance during the study period.

The growth rate was determined as:

$$\text{Growth Rate (g / day)} = \frac{\text{final weight (g)} - \text{initial weight(g)}}{\text{Rearing period (days)}}$$

Survival rate and body condition indexes

Any mortalities that occurred during the experimental period were recorded and used to calculate the survival rate as:

Survival rate =100× (Total number of fish stocked -Total number of dead fish/Total number of fish stocked).

Samples of six fish per treatment groups were randomly selected from the twelve cages. They were dissected; eviscerated and gut contents were emptied and cleaned. Visceral and hepatic weight were measured so as to estimate Visceral somatic index and Hepatosomatic index as biological indices that determine gut health [30].

The visceral somatic index was calculated as:

$$\text{Visceral somatic index} = \frac{\text{Visceral weight*100}}{\text{Body weight}}$$

while

$$\text{Hepatosomatic index} = \frac{\text{Hepatol weight*100}}{\text{Body weight}}$$

Hematological parameters

Fish were harvested at the end of the experiment and fasted for 24 h prior to the blood collection. The blood samples were taken from three fish per treatment totaling to 12 fish corresponding to each cage. They were anesthetized using clove oil following which blood tissue was taken from caudal vein of fish from each of the diet treatment groups. The collected blood was preserved in anticoagulant (EDTA) vacutainers. Using micro-capillary tube and hematology analyzer, blood parameters such as red blood cells (RBC) count, hemoglobin, white blood cells (WBC) count, mean corpuscular volume (MCV), and mean corpuscular hemoglobin concentration (MCHC) were determined.

Cost-benefit analyses of replacing fish meal with black soldier fly

Two indices were used to assess the economic impacts of feeding BSFL at different inclusion level in Nile tilapia. These indices were cost benefit analysis (CBA) and return on investment (ROI). The ROI is a ratio of gross margin divided by the feeding costs and expressed as a percentage. The ratio is an indicator of gain or loss incurred from the inputs in relation to the cost of money invested. The cost factor only included that of feeding which varied across all treatment groups since all others costs were uniformly distributed across treatment groups. The costs of the feeds were calculated based on the raw material valued at market price at the time of the experiment. Benefits included anticipated return for the sale of fish. The ratio of return versus cost was used to estimate cost benefit ratio (CBR) where values greater than1 implied benefits exceeded the cost and vice versa.

Statistical analysis

Data on length and weight gain, feed intake, survival rate, visceral somatic and Hepatosomatic index, gross profit margin, cost benefit ratio and return on investment were subjected to One-way Analysis of variance (ANOVA) test and least significant difference (LSD) was used to compare means among the treatment groups. A 5 % confidence interval was applied and significant differences were considered for p-values less than 0.05.

Results and discussion

Proximate composition of experimental diets

The results for the proximate composition of the diets used in this experiment are shown in Table 2. The dry matter (DM) content

Table 2
Average proximate composition (%) of the experiment diets.

Parameters	T0 %	T25 %	T50 %	T75 %
Dry matter	90.79	90.33	91.13	91.62
Ash	10.32	10.35	10.40	10.21
Crude protein	30.50	29.80	29.14	28.83
Crude fiber	6.02	7.12	8.61	9.50
Ether extract	10.36	10.57	11.23	11.82
Energy (Kcal/kg)	2720.00	2819.00	2865.00	2960.00

T0 (100 % FM; 0 % BSFLM); T1 (75 % FM; 25 % BSFLM); T2 (50 % FM; 50 % BSFLM); T3 (25 % FM; 75 % BSFLM).

was highest (91.62 %) in treatment T75 % and lowest in treatment T25 % (90.33 %). Similar studies have reported DM contents of more than 90 % [26], which implies better shelf-life of the diets. The ether extracts were highest in T75 % and lowest in T0 % (control). The inclusion of BSFLM in the increased the lipid content of the diets due to its high fat content. Similarly, other studies [31,26] observed higher ether extracts in the diets in which BSFLM was included up to 100 % than a FM control diet. The CP content was found to be high in the control diet (30.59 %) than the diets in which BSFLM was included (lowest in T75 %- 28.83 %) and this was attributed to the high CP content in fish meal. With the optimum requirement for starter tilapia being 35 % CP and adult 25 % CP, the results demonstrate that BSFLM can replace FM in tilapia fish diets since the protein levels of the diets meet the requirements for adequate tilapia fish nutrition [22]. The crude fiber was highest (9.5 %) in T75 % than the control group (6.02 %). The higher BSFLM levels increased the levels of fiber in T25 %, T50 % and T75 % because of the fibrous exoskeleton (chitins) in BSFLM. Ash levels ranged from 10.21 to 10.40. Energy was highest in T75 % (2960 Kcal/kg) and low in T0 % (2720 Kcal/kg) because of the lipid content being higher with higher BSFLM levels and since fat is a source of energy might have contributed to the increased in energy across the diets from the control to the highest BSFLM inclusion of 75 %.

Growth performance

The measured growth performance indicators, including body length gain, body weight gain and feed intake were not significantly ($p > 0.05$) affected by substitution of FM with BSFLM up to 75 % as shown in Table 3 below. The weight gain of fish among the treatment groups was not significantly different ($p > 0.05$). However, treatment T50 % (52.16 g) had the highest body weight gain while treatment T75 % (46.00 g) had the lowest body weight gain even though not statistically different ($p > 0.05$).

The body length was higher in T50 % (16.50 cm) and lowest in T75 % (15.91 cm) though not statistically ($p > 0.05$) different even when compared to the control. Treatment T75 % showed lowest performance in terms of body length and weight gain than other treatment groups. Findings from a research study by Shati et al. [32] showed significant impact of including BSFLM in Nile tilapia diets. The authors also revealed that Nile tilapia fed diets in which BSFLM was included up to 100 % had the highest weight gain followed by 50 % BSFLM fed group and lastly 0 % BSFLM fed group and the results were significantly different. However, high levels of BSFLM have been reported to lower the body weight gain (BWG) in Nile tilapia (*Oreochromis niloticus*) [33] and in grass carp (*Ctenopharyngodon idel-lus*) [34] due to the imbalance of amino acids as well high fiber (chitin) levels in the BSFL. In addition, daily feed intake was not significantly affected ($p > 0.05$) by including BSFLM in different treatment diets.

Our results strongly agree with those of Limbu et al. [25] who reported no significant differences in feed intake in Nile tilapia fingerlings fed diets supplemented with BSFLM up to 75 %. Despite the non-significant influence of inclusion of BSFLM up to 75 % on feed intake in Nile tilapia diets, previous findings reported that inclusion of BSFLM up to 100 % in Nile tilapia suppressed feed intake [35,36] and this was related to the reduced palatability of the feeds [37]. The higher weight gain and daily weight gain can be attributed to optimal inclusion levels for BSFL. From our study, the findings suggest that feeding Nile tilapia fingerlings with BSFLM up to 75 % improved growth performance with numerically higher performance for 25 % and 50 % inclusion levels. Similar observations have been reported [38,26]. This was also similar to the finding by Muin et al. [35] who reported that BSFLM could be optimally utilized at 50 % inclusion levels and further increase in inclusion levels of BSFLM for red tilapia led to a decrease in weight gain. Further, a research study by Tippayadara et al. [39] illustrated that inclusion of BSFLM up to 100 % in Nile tilapia diets did not have adverse effects on growth performance, survival rate and somatic indexes. Additionally, when 50 % BSFLM was used to replace soy protein in Nile tilapia diets, and there were no adverse effects on feed conversion ratio and growth performance [40]. Different studies have also recorded enhanced growth performance when BSFLM was included in Siberian sturgeon fingerlings [41], rice field eel (*Monopterus albus*) juvenile [42] and yellow catfish fry [30]. The better performance of the fish consuming diet T25 % and T50 % could be attributed to an adequate balance of essential nutrients. The improved fish growth performance has also been reported when two or more animal protein sources are combined [43] which was the case in diets T25 % and T50 %. However, the T75 % had slightly lower CP content and higher fiber levels (Table 2), which could have contributed to numerically depressed growth performance of the fish fed on the diet.

Survival rates and body condition indexes

Table 4 below presents the performance of treatment diet groups on health and survival of Nile tilapia. Survival rate was

Table 3
Growth parameters of growing Nile tilapia fish fed on the experimental diets.

Parameters	T0 %	T25 %	T50 %	T75 %	F-value	P-value
Initial body length (cm)	14.64±0.28	14.85±0.23	14.68±0.25	14.63±0.26	3.11	0.06
Final body length (cm)	16.20±0.37	16.33±0.36	16.50±0.36	15.91±0.30	1.90	0.13
Initial body weight (g)	24.48±0.64	25.50±0.60	24.74±0.75	24.20±0.68	2.57	0.06
Final body weight (g)	71.96±4.57	77.08±4.70	76.90±4.80	70.10±3.75	2.40	0.07
Weight gain (g)	47.48±4.59	51.60±4.66	52.16±5.02	46.00±3.75	1.80	0.149
Daily body weight gain	0.26±0.03	0.28±0.03	0.29±0.03	0.26±0.02	1.80	0.149
Daily feed intake(g/day)	0.11	0.13	0.12	0.12	1.85	0.14

T0 (100 % FM; 0 % BSFM); T 1 (75 % FM; 25 % BSLM); T 2 (50 % FM; 50 % BSLF); T 3 (25 % FM; 75 % BSF). Values were expressed as means ± SEM.

Table 4
Survival rate and body condition indexes.

Parameters	T0 %	T25 %	T50 %	T75 %	F-value	p-value
Survival rate %	85.56^{b}	96.67^{ab}	100.00^{ab}	96.60^{ab}	10.50	0.00
Visceral somatic index %	4.81±0.38	4.99±1.40	5.57±1.50	5.19±1.04	0.05	0.07
Hepatosomatic index %	0.67±0.12	0.73±0.16	0.75±0.25	0.81±0.19	0.04	0.8

T0 (100 % FM; 0 % BSFM); T1 (75 % FM; 25 % BSLM); T2 (50 % FM; 50 % BSLF); T3 (25 %FM; 75 %BSF). Values were expressed as means ±SEM, similar superscripts indicate not significant and different superscripts indicate significant differences as determined by least significance differences.

significantly ($p < 0.05$) affected by the dietary treatment. Treatment T50 % had the highest survival rate (100 %) while the control group (T0 %) had the lowest survival rate (85.56 %). In all BSFL treatment groups T25 %, T50 % and T75 %, survival rates were higher (above 96 %) compared to the control group, T0 % (85 % survival). Our results conquer with findings in Nile tilapia [39], juvenile grass carp (*Ctenopharyngodon idellus*) [34] and yellow catfish (*Pelteobagrus fulvidraco*) [30] in which BSFLM was utilized in preparation of diets for the different fish species. Fish physiological processes play a major role in their survival rates, therefore, appropriate feeding regimes and acclimatization of fish to their habitats is essential. Devic et al. [33] also showed that nursing tilapia fingerlings fed diet containing BSFLM at 80 % had the highest survival rate (90 %) while the group fed 30 % BSFLM (81 %) had the lowest survival rate while the control group had 86 % survival rate and the results differed significantly. In fish, the body index is a vital parameter in reflecting its growth. The higher survival rates of the fish consuming diets with BSFLM included could also be due to the chitin present in the BSFLM which is known to offer other beneficial effects to the fish such as boosting the immunity of the fish [26].

Visceral somatic index (VSI) and hepatosomatic index (HSI) are used as indicators of gut and general health since the viscera impacts on metabolism in relation to digestion, synthesis and secretion of enzyme as well as nutrient absorption. They are therefore often used to assess the physiological states and nutritional quality of fish. Our current study shows that the HSI and VSI increased in fish fed diets with BSFLM inclusion levels up to 75 % compared to the control group though the difference was not statistically different ($p > 0.05$). The fish in treatment T50 % had the highest VSI (5.57 %) while the control T0 % had the lowest (4.81 %) although these differences were not significant ($p > 0.05$). The conclusion from these observations would be that, inclusion of BSFL meal in diets has no effect on VSI and subsequently gut health in Nile tilapia. The hepatosomatic index values were not significantly ($p > 0.05$) different between and among treatment diet groups ($p > 0.05$). This is consistent with other findings by Tippayadara et al. [39] who found no significant difference in somatic indices. Furthermore, [44] observed an increase in VSI and HSI in Atlantic Salmon (*Salmo salar*) fed higher dietary levels of BSFLM. Various authors have reported that higher BSFLM increases the lipid levels in the experimental fish diets [45,46] thus increasing the lipid levels in fish carcass composition. As noted by Xu et al. [47], the muscle tissue and viscera influences deposition of lipids in the body. Tocher [48] recorded that excess deposition of fats in the liver tissue and visceral cavity is influenced by the higher levels of lipids in the diets and this affects the whole body lipid composition. As observed by Han et al. [49], fish diets containing high lipid levels led to an increase in the VSI and HSI in hybrid tilapia. The hepatosomatic and visceral somatic indexes from fish fed on the treatment diets in the current study did not differ from those feds on the control diet indicating that inclusion of BSFL meal did not cause abnormal fat deposition thus the functioning of the liver and intestinal physiology of Nile tilapia were not tampered with. This is in agreement with a study by Renna et al. [50] who illustrated that BSFL meal inclusion did not have adverse effects on visceral somatic and hepatosomatic indices of yellow catfish and rainbow trout respectively.

Hematological indexes

The effects of feeding Nile tilapia on BSFLM on several hematological parameters were assessed. Results for the analyzed blood parameters are shown in Table 5. Generally, values for the red blood cells (RBCs) count, Hb, Hct, MCV and MCHC were similar between the control and test diets thus not statistically different ($p > 0.05$). It is noteworthy that hematological parameters are vital in assessing the physiological stress responses and general health status of fish fed formulated diets [51]. The current study results are similar to

Table 5
Haematological parameters.

Diet	T0 %	T25 %	T50 %	T75 %	F value	P value
RBCS 10$^{\hat{}6}$ul	1.62±0.50	1.7 ± 0.34	1.53±0.28	1.49±0.50	0.30	0.85
HB(g/dl)	4.70±1.90	4.30±1.20	3.90±0.11	5.30±2.20	0.58	0.64
Hct (%)	21.93±8.60	20.74±1.90	23.10±14.00	21.64±9.00	0.04	0.99
MCV (fl)	149.50±96.60	120.41±14.80	147.02±68.50	152.40±82.20	0.15	0.93
MCHCg/dl	24.80±17.80	21.20±6.20	20.62±12.30	25.20±4.71	0.17	0.92
WBCS (10$^{\hat{}6ul}$)	3.50±0.10	3.63±0.30	4.20±0.30	3.33±0.20	7.42	0.11
Neutrophils granulocytes (x10^{3}.ML–^{1})	44.00±8.50	40.00±18.20	50.00±8.34	38.33±7.36	0.74	0.53
Lymphocytes agranulocytes (x10^{3}.ML–$^{1)}$)	43.00±6.80	34.30±17.5	23.30±7.40	38.00±18.10	1.46±	0.30
Monocytes agranulocytes (x10^{3}.ML–$^{1)}$)	12.30±1.73	16.00±2.30	15.00±2.30	15.00±4.00	0.02	0.99

T0 (100 % FM; 0 % BSFM); T1 (75 % FM; 25 % BSLM); T2 (50 % FM; 50 % BSLF); T3 (25 % FM; 75 % BSF) RBCS; red blood cells, Hb; hemoglobin, Hct; haematocrit, MCV; mean corpuscular volume, MCHC; Mean corpuscular hemoglobin concentration, WBCS; white blood cells. Values were expressed as means ± SEM.

Table 6
Economic analysis of partial substitution of fishmeal (FM) with black soldier fly larvae meal (BSFLM) in Nile tilapia.

Parameters	T0 %	T25 %	T50 %	T75 %	F-value	P-value
Total feed cost USD/fish (C)	0.39±0.04	0.35±0.06	0.36±0.07	0.32±0.02	143.00	0.00
Live weight at harvesting (g)	71.96±4.57 [a]	77.08±4.70 [a]	76.90±4.88 [a]	70.10±3.75 [a]	2.40	0.07
Sale of fish (S)	0.43±0.10[b]	0.45±0.10[ab]	0.45±0.10[ab]	0.41±0.06[c]	19.71	0.00
Gross profit margin (P)	0.03±0.02[b]	0.11±0.020[ab]	0.10±0.000[ab]	0.09±0.000[ab]	41.77	0.00
Cost benefit ratio (CBR)	1.10±0.03[b]	1.31±0.04[ab]	1.28±0.01[ab]	1.31±0.01[ab]	49.26	0.00
Return on investment (RoI)	9.32±3.40[b]	31.53±4.46[ab]	28.54±1.10[ab]	30.90±1.30[ab]	49.50	0.00

T0 (100 % FM; 0 % BSFM); T1 (75 % FM; 25 % BSLM); T2 (50 % FM; 50 % BSLF); T3 (25 % FM; 75 % BSFLM); CBR=*S*/C; *P* = *S*-C; RoI=*P*/C x 100; over computation was based on the current market price of USD 5.9 per kg of tilapia fish; currency exchange was USD 1 at 135 KSH. Values were expressed as means ±SEM, different superscripts indicate significant differences as determined by least significance differences.

those obtained in the study by Tippayadara et al. [39] who observed that inclusion of BSFLM in Nile tilapia diets had no significant influence on hematological parameters red blood cells, white blood cells, red blood cell distribution width, hematocrit, hemoglobin, mean corpuscular volume and hemoglobin, mean corpuscular hemoglobin concentration and platelet values. Likewise, the study by Yildirim–Aksoy et al. [52] showed no influence on blood parameters when hybrid tilapia (*O. niloticus* × *O. Mozambique*) was fed on diet containing 30 % BSFL meal for 12 weeks. Likewise, there were no significant impacts on blood parameters white blood cells, monocytes, neutrophils and lymphocytes in European sea bass, *Dicentrarchus labrax* fed diets containing BSFLM as compared to the FM fed group [17]. Belghit et al. [53] also did not find changes in Hb when Atlantic Salmon were fed on diets in which BSFL meal was used to replace fish meal.

The current study findings indicate that the WBCs counts, lymphocytes, monocytes, and neutrophils values obtained from fish fed on BSFLM diets had no significant difference to those fed on the control diet ($p > 0.05$). This was similar to findings of a study by Abdel-Tawwab et al. [17]. Conversely, another study by Ushakova et al. [54] in which Mozambique tilapia (O. mossambicus) were fed diets containing BSFLM for one month showed an increased hemoglobin levels in the blood. Kamalii et al. [55] found significant effects on blood indices RBC, WBC, Hb, Ht, MCV, MCH and MCHC when Juvenile Goldfish, *Carassius auratus* were fed diets containing 60 % BSFLM compared to the other experimental diets.

Economic analysis

Based on our findings, feeding Nile tilapia fish on diets in which BSFLM was included at 25 %, 50 % and 75 % affected positively the profit margin compared to the control diet (T0 %) as shown in Table 6. The profit margin was significantly different ($p < 0.05$) due to the low cost of production of fish diets with BSFLM. Diets T25 %, T50 % and T75 % had higher profit margins when compared with diet T0 % (control). Indeed, our study agrees with the findings of Limbu et al. [25] who reported that feeding Nile tilapia fry on diets in which BSFLM was included up to 75 % and 100 % increased the profit index compared to the Nile tilapia fry fed diet consisting of 100 % FM. In line with our findings, Wachira et al. [26] also reported that Nile tilapia fish fed diet consisting of 100 % BSFM had higher gross profit margin compared to the group fed control diet. Moreover, Nile tilapia juveniles fed diets in which FM was substituted with 25 %, 50 % and 100 % of partially defatted BSFLM resulted to reduction in feed costs and higher profits hence higher economic efficiency than the control group [56]. Abdel-Tawwab et al. [17] recorded similar findings in European sea bass (*Dicentrarchus labrax*) in which BSFLM reduced feed cost and increased net returns. Shati et al. [32] found that the cost of feeds was reduced by 8.8 % and 12 % when soybean meal was replaced by 50 % and 100 % respectively in Nile tilapia diets and this was attributed to the lower price of BSFLM. According to results from a study by Limbu et al., [25], the authors recommended that farmers can be able to reduce the cost of production of Nile tilapia by 30 % by including 75 % of BSFLM in the diet, hence realizing higher economic returns. From the results, 100 % utilization of fish meal in the diet had the least gross profit margin, CBR and ROI compared to the diets in which BSFLM was incorporated at 25 %, 50 % and 75 % levels. In any modern aquaculture production, fish farmers consider economic returns as an integral part as the cost of feeds which covers half of the operating cost affect profitability [25]. Therefore, lowering the costs of feeds is critical to achieve profitability and ensure sustainability of fish farming. Black soldier fly larvae meal is an alternative cheap source of protein, hence their lower costs when utilized in fish feeds.

The BSFLM meal is currently cheaper to produce and therefore diets that incorporate it as a source of protein tend to be cheaper besides maintaining comparatively good growth performance with fish reared on diet prepared using fish meal as the source of protein. The findings obtained by Shumo et al. [21] indicated that BSFL meal may be similar or superior to fish meal and plant protein sources and are potentially low-cost protein source which is in agreement with the findings of this study. These findings are further collaborated by results by Odhiambo et al. [57].

Conclusion

In this study, it has been shown that FM can be substituted with BSFLM in Nile tilapia diets up to 75 % without compromising their growth but with better performance at 50 % and 25 %. The gross profit margin, cost benefit ratio and return on investment improved with inclusion of BSFLM instead of FM, thus making BSFLM a cost-effective high-quality ingredient in compounded fish feed to grow Nile tilapia fish. The current findings would contribute to inform policy makers to support BSFLM integration into large scale commercial feed manufacturing and enhance sustainable intensification of aquaculture production, contributing significantly to food and nutritional security.

CRediT authorship contribution statement

Mercy W. Kariuki: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Writing – original draft. **Didier K. Barwani:** Investigation, Writing – original draft. **Vincent Mwashi:** Methodology, Writing – original draft. **Jim K. Kioko:** Data curation, Project administration, Validation. **Jonathan M. Munguti:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft. **Chrysantus M. Tanga:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration. **Peter Kiiru:** Investigation, Validation. **Mathew G. Gicheha:** Conceptualization, Data curation, Formal analysis, Investigation, Supervision, Validation. **Isaac M. Osuga:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation.

Declaration of competing interest

We confirm that we have no conflicts of interest to disclose.

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