ORIGINAL RESEARCH ARTICLE

Black Soldier Fly (*Hermetia illucens*) Larvae for Nile Tilapia (*Oreochromis niloticus*) On-Farm Feeding: Effect on Performance and Profitability.

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ABSTRACT
Aquaculture is one of the fastest growing sector in agriculture. However, this increase is constrained by the high cost of fish feeds occasioned by scarcity of fish meal (FM) which is a main source of dietary protein in aquafeeds. This necessitates the need to consider alternative protein sources that are sustainable, cheap, available and highly nutritious. Recent studies have shown that black soldier fly (*Hermetia illucens*) larvae (BSFL) and FM have a nutrient profile that is closely comparable and therefore, the fly meal is feasibly cheaper alternative to FM in making fish feeds. This study sought to find out the effect of replacing FM with BSFL meal on growth performance of Nile Tilapia (*Oreochromis niloticus,* L) and the corresponding profitability. The experimental diets adhered to the nutritional requirements of Nile Tilapia nutritional requirements. A total of five dietary treatments were tested. The treatments differed on the inclusion levels of BSFL meal. The experimental diets corresponded to 0% (T0; control), 25% (T25), 50% (T50), 75% (T75) and 100% (T100) group. The diets were fed to a total of 600 fingerlings. The fingerlings were assigned to 20 cages built in an earthen pond, with 30 fingerlings in each. The experimental units were randomly assigned to each of the cages. Each treatment was replicated four times. The fingerlings were fed the experimental diets for 26 weeks. The results of the current study indicate that feed intake was lowest in fish fed on diets T0 and T100. However, despite treatment T75 having the highest body weight gain compared to all other treatment diets, there was no statistical significance ($p>0.05$) for the body weight gain amongst the treatments. Nevertheless, there was a significant difference ($p<0.05$) in specific growth rate (SGR) within and between treatment diets. The SGR were 0.35,

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0.41, 0.42, 0.44 and 0.52 for treatments diets T0, T100, T25, T50 and T75 respectively. Treatment diet T25 recorded the lowest feed conversion ratio (FCR) compared to the other treatments diets. Further, the results indicated that survival rates from different treatment groups in the study were significantly different (P<0.05) with the highest being recorded in T75 and T100 at 95.83% and 95.00% respectively while T0, T25 and T50 resulted to survival rates of 91.67%, 90.83% and 93.33% respectively. The increasing levels of BSFL substitution with FM resulted in a corresponding reduction in feeding costs, which yielded higher gross profit margins. Treatment group T75 realized the highest return on investment (ROI) followed by T100. The cost benefit ratio (CBR) of diet group T100 was the highest followed by T75 with the lowest being realized from T0 diet. The study found that 75% (T75) replacement of FM with BSFL meal was ideal for optimal weight gain, feed conversion ratio (FCR), specific growth rate (SGR) and conditional factor (K).

Key words: Aquaculture, Aquafeeds, BSFL, BSFLM.

1.0 Introduction

Aquaculture has been the fastest growing sector in the food industry with an estimated annual growth rate of 5.8% (FAO, 2018). Approximately 49% of the global fish production is from aquaculture. An estimated 90% of the total aquaculture production is from developing economies with some of the lowest per capita incomes (FAO, 2013). The global output from aquaculture has continually increased over the last half century, with current output similar to that of capture fisheries (Shati et al., 2022). With the declining production levels of fish capture, aquaculture has remained the only option in meeting the demand for fish products (FAO, 2022). The potential of aquaculture has been demonstrated in meeting the nutritional needs in terms of affordable protein sources to the ever-increasing human population (Hua et al., 2019; Fiorella et al., 2021; Goyal et al., 2021). The demand for animal protein is set to rise to 60% due to the effect of improved income, improved nutritional patterns and urbanization. According to the state of world fisheries and aquaculture (FAO, 2022), the fish supply from aquaculture is set to increase as the potential of the sector continues to be exploited for its superior animal protein. The rapid growth of the aquaculture industry has been prompted by the increasing demand for fish as a source of food, but this growth has put pressure on the sustainability of fish feed used in aquaculture sector. Therefore, fish protein from capture fisheries is no longer sustainable (Smárason et al., 2019). Progressive change in climate and continued destruction of the environment could see food productivity affected negatively. Expansion of the aquafeeds industry is necessary in order to meet the accelerated demand of fish (Liland et al., 2017). Fish feeds constitute 60% of the production costs in aquaculture, and are primarily made up of wild-caught fish, which is not sustainable (Munguti et al., 2012, 2021).

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The main source of protein in animal feeds is fish meal. This has been attributed to its better nutritional composition in terms of high protein content (65%–70%), high essential amino acids and polyunsaturated fatty acids (Miles and Chapman, 2012). Fish meal as the main protein source in fish feeds is uneconomical to produce and poses significant environmental challenges. About 12% (20 million tonnes) of the total fish catches (171 million tonnes) was used for production of fish meal and fish oil in 2016 (FAO, 2018). Research shows that if the trend continues, it will render the supply of small fish obsolete by 2037 (Pallab, 2021). The over-exploitation of the wild fish stocks is not only affecting the health of the ocean's ecosystem but also the long-term sustainability of the aquaculture industry (Smárason et al., 2019). Utilization of soybean meal (SBM) in aquafeeds formulation is beneficial though limited by essential amino acid balance, phytates, tannins and trypsin inhibitors (NRC, 2011). Reported finding indicate that inclusion of high plant protein sources has detrimental effects on the growth rate, digestion, gastrointestinal secretion and immunity especially in carnivorous fish (NRC, 2011). The conventional protein sources FM and SBM used in fish feeds are also used as food source for humans resulting to competition for the same sources of protein in foods and feeds. This results to high fish feeds cost. Furthermore, the over-reliance on these traditional protein sources can lead to environmental degradation, as well as the depletion of wild fish stocks, which are used to produce fishmeal (Smárason et al., 2019). To reduce the high costs of production and ensure sustainable production, high quality alternative sources of protein need to be adopted in production of Nile Tilapia diets (Schiavone et al., 2017). A promising alternative potential source of protein for use in the production of the fish feed are insects' meal (Arru et al., 2019; Gasco et al., 2020). Research evidence shows insect meals have high protein, mineral, fats and energy (Gao *et al*., 2019; Gasco et al., 2018) making it a suitable alternative. Spranghers et al. (2017) revealed that insect meals contain essential amino acids such as methionine, lysine and leucine with no anti-nutritional factors. Further, it is evident that insect production requires lesser inputs to achieve the same protein levels as conventional livestock protein sources. Insect farming results to a comparatively less greenhouse gases emission (Gasco et al., 2020). Compared to other conventional protein sources, they are more sustainable if reared on low-value substrate (Bosch et al., 2019; Gasco et al., 2020). For instance, insects can be fed on organic waste such as poultry manure, fish offal, vegetables, pig manure and other organic wastes like fruit peels and restraint food remnants, which is not feasible in fish and livestock feeding. Various insects such as crickets, grasshoppers, black soldier fly larvae (BSF) and housefly have high nutritional value which can be used to substitute FM as a protein source (Xu et al., 2021) Research has demonstrated that these insects can be reared in large scale production systems.

The emergence of BSFL meal as an alternative protein source has been investigated. Evidence shows that it can be used as a substitute feed ingredient in replacing FM and SBM in animal feeds (Munguti et al., 2021; Onsongo et al., 2018). Diener et al. (2009) and NRC, (2011) reported that

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dried BSFL meal has similar nutritional profile to FM, as it is highly rich in proteins (up to 60%), lipids (10%-30%) and balanced amino acids profile. In comparison, BSFL shows a better in amino acids profile compared to plant-based protein sources (Fisher et al., 2020; Makkar et al., 2014). Furthermore, it has been reported that dried BSFL meal is rich in vitamins and minerals (Fisher et al., 2020; van Huis, 2013). The larva of BSF has the highest economic return and potential with the highest conversion rate of organic waste into valuable protein nutrients. The main source of nutrients for the BSFL could be poultry manure, fish offal, vegetables, pig manure and other organic wastes like fruit peels and restraint food remnants (Shumo et al., 2019). Makkar et al. (2014) elucidated on BSFL's ability to thrive on an extensive assortment of wastes, utilizing them and converting these wastes into vital nutrients for use in animal feeds. Due to its aforementioned properties, BSFL meal has drawn the attention of many fish culture systems.

According to FAO (2022) Nile Tilapia is the most vital and economic cultured fish globally. It is also the most preferred and farmed fish species in the subtropical and tropical regions in the world. Nile Tilapia is the main fish species farmed in Kenya's inland areas though there is some extent production of African catfish (Opiyo et al., 2018). The species farming accounts for about 75% of production in Kenya (Munguti et al., 2014). The surge in the popularity of the Nile Tilapia can be attributed to its ability to thrive in a wide range of culture systems, rapid growth, high fecundity and ability to withstand various fish diseases (Munguti, 2007). Additionally, some studies reported that Nile Tilapia can be able to grow and survive in water conditions with low oxygen levels and produce fingerlings even when under captivity (Githukia et al. 2015; Fitzsimmons, 2016). Furthermore, there is a quite promising domestic market for Nile Tilapia (Quagrainie et al., 2010). Various research studies have been conducted to assess the suitability of using BSFL meal in different fish species growth, health and welfare performance (e.g. Devic et al., 2018, Cummins et al., 2017, Xiao et al. 2018, Wachira et al., 2021). Previously, BSFL meal has been used successful in replacing FM in Nile Tilapia diets without challenges associated with their survival and growth performance (Devic et al., 2018; Cummins et al., 2017). Xiao et al. (2018) reported that the substitution of FM with BSFL meal in fish diets showed higher growth performance while also reducing the feed conversion ratio (FCR) without significant effects on the survival rate and body indexes of yellow catfish. Recently, Wachira et al. (2021) utilized 33% instead of 100% BSFL meal in formulation of Nile Tilapia diets and found greater gross profit margin but the cost-benefit ratio and return on investment (ROI) were not significantly different. However, most of the reported studies have been done in research stations with few studies done under farmer conditions. Therefore, this study was employed to ascertain the suitability of full-fat BSFL meal in substitution of FM in Nile Tilapia growth performance and profitability on-farm.

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2.0 Materials and methods

2.1 Study site

The experiment was carried out in Bukani Aquapark, Busia County. Bukani Aquapark is placed at 1,227 meters above sea level on latitude 0.4346506 and longitude 34.2421597. The ambient temperature is averagely 23 degrees Celsius and 40 % humidity with an annual rainfall of 1,750 mm ("Worldwide Elevation Finder", 2022).

2.2 Formulation of experimental diets

The various feed ingredients used in making the diets were sourced from local suppliers within Busia County, Kenya. The BSFL meal used in the formulation of the feed were obtained from the International Centre for Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya. The fish meal and BSFL meal were the main feed ingredients used as a protein source in the experimental diets formulation. A proximate analysis was carried out on the mixed feed ingredients to obtain its composition. Table 1 below shows the five iso-calorific and iso-nitrogenous diets that were formulated for the experiment. Treatment T0 (100% FM; 0% BSFL) acted as the control diet against which the other diets were compared. The other diets were prepared with the substitution of FM with BSFL meal at levels of 25%, 50%, 75% and 100% to create diets T25, T50, T75 and T100 respectively. These experimental diets were formulated to nutritionally meet the requirements of Nile Tilapia fish optimal growth. The various feedstuff ingredients used were ground and mixed thoroughly to make a homogenous blend. A 2-4 mm commercial pelletizing machine was used to pelletize the resultant mash into semi-floating pellets which were properly sundried and stored for later use in the experimental feeding trials. Samples from the feeding trial were collected for analysis using the proximate analysis protocol recommended by Association of Official Analytical Chemists (AOAC, 2012).

Table 1: Treatment diet formulation (%) and calculated nutrient composition

	Treatment group diets				
Ingredient	T0	T25	T50	T75	T100
Pollard	7.00	7.00	7.00	7.00	7.00
Rice Polishing	20.00	19.25	19.00	18.75	18.50
Maize germ	22.00	22.00	21.50	21.00	20.50
Fish meal	7.00	5.25	3.50	1.75	-
BSFLM	-	2.50	5.00	7.50	10.00
Soybean Meal	35.00	35.00	35.00	35.00	35.00
Sunflower Cake	5.00	5.00	5.00	5.00	5.00
Lysine	1.00	1.00	1.00	1.00	1.00

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Methionine	1.00	1.00	1.00	1.00	1.00
Fish Premix	2.00	2.00	2.00	2.00	2.00

T0 - control (no black soldier fly larvae meal included), T25 - 25% BSFLM substitution of FM, T50 - 50% BSFLM substitution of FM, T75 - 75% BSFLM substitution of FM, and T100 - 100% substitution of FM; BSFL – black soldier fly larvae; FM - fishmeal; Fish premix composed of vitamins A, D3, E, B1, B2, B6, K3, C and trace minerals Zinc, Cobalt, Iron, Manganese, Magnesium, Selenium, Calcium, and Phosphorus

2.3 Experimental design and fish

An earthen pond measuring 40m by 20m was used in the holding the fish during the feeding trial. The pond was limed with 100g/m^2 of Calcium Carbonate ($CaCO_3$) prior to the filling of the pond with water and fertilized. The ponds were fertilized with 2g/m^2 of Dicalcium Phosphate (DAP) per week. Twenty hapa net cages measuring 2×2×1.5 meters were set up in the earthen pond. Six hundred (600) Nile Tilapia mixed sex fingerlings of uniform size and age were sourced from Kenya Marine and Fisheries Research Institute (KMFRI) Sagana station, Kenya and allocated to the 20 cages. A completely randomized design was applied in allocating fingerlings to the cages. Fingerlings in each cage were fed on the experimental diets thus representing the different treatments. The fingerlings were allocated across the twenty cages implying that each treatment experiment was replicated four times. The fingerlings were acclimatized to the environmental conditions for 2 weeks while being fed a commercial diet before the feeding with the experimental diets commenced. The experimental diets were labeled as T0% (0% BSFLM, 100%FM), T25% (25% BSFLM, 75%FM), T50% (50% BSFLM, 50% FM), T75% (75% BSFLM, 25% FM) and T100 (100% BSFLM, 0% FM). The diets were administered at rate of 5% of the total body weight and adjusted fortnightly. Water parameters were regularly monitored to ensure they were within the suitable ranges for Nile Tilapia optimal performance. The feeding trial was carried out for 24 weeks with feeding being carried out at 0900 hours and 1600 hours.

2.4 Sampling during feeding trial

Data on the physio-chemical parameters of the water were collected using a water quality meter; model H19828, Hanna Instruments Ltd., Chicago, IL, USA. This was done on a weekly basis. Correction measures were implemented if any undesirable deviations were detected. During the 24-week feeding trial, growth parameters including weight was measured using a digital weight balance (model EHB-3000, China) and length using a board trough standardized meter ruler. The measures were recorded throughout the experiment. The growth parameters were observed every two weeks to monitor the performance trends. The feed quantity provided to the fish was revised biweekly according to the progressive weights of the Nile Tilapia.

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Additionally, the mortality was recorded throughout the experimental period. The survival rate during the experiment was calculated by calculating the difference between the fish stocking population and the total number of fish at the end of the experiment. Feed conversion ratio (FCR) and specific growth rate (SGR) calculations were obtained from the weight and length data.

2.4.1 Assessment of growth parameters

The different growth performance parameters across the treatments were measured and calculated as described by Qi et al. (2012) and Sveier et al. (2000) as follows:

Body Weight gain (g) = final weight (g) - initial weight (g) (1)

$$\text{Specific Growth Rate \% (SGR)} = \frac{\text{(Final weight − Initial weight) grams}}{\text{Time in days of culture}} \times 100\% \quad (2)$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Feed intake (g)}}{\text{Weight gain (g)}} \quad (3)$$

$$\text{Condition Factor (CF)} = \frac{\text{Total weight of dry diet fed (g)}}{\text{Total wet weight gain of the fingerlings (g)}} \quad (4)$$

$$\text{Survival rate \% (SR)} = \frac{\text{Final number of fingerlings}}{\text{initial number of fingerlings}} \text{ x } 100\% \quad (5)$$

2.4.2 Profitability evaluation

Various factors such as feeds and labour have been used to calculate the production costs; however, this study only adopted costs of feeds in determining calculations for profitability of BSFL meal utilization in fish diets of Nile Tilapia while assuming no variation in labour across the treatments during the feeding. The market prices of feed ingredients in Kenya at the time in of the experiment were used in calculating the feed costs of the experimental diets. Two indices were evaluated to determine the efficiency and profitability of insect-based BSFL meal inclusion in feeding of Nile Tilapia. Economic analysis was done based on indices; cost benefits analysis (CBA) and return on investment (ROI). In relation to money invested, ROI indicates the loss/gain accrued from the inputs invested. The ROI is a ratio of gross margin divided by the feeding costs and expressed as a percentage. To estimate cost benefit ratio (CRB), the ratio of return versus cost was applied. Cost benefit ratio values exceeding 1 implied that the benefits surpassed the cost and vice versa.

2.5 Statistical analysis

The data from the experiment was entered in MS Excel, processed to remove any errors and inconsistencies and analysed using R studio software version 4.3.1. The statistical differences were

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analysed using one-way Analysis of Variance (ANOVA). The means separation was done using Tukey post-hoc test at less than 0.05 significance level.

3.0 Results

3.1 Water quality parameters

Table 2 presents the mean values of physio-chemical parameters of water during the entire experiment period. The average water temperature within the pond was 24.85 °C. The average value for dissolved oxygen was 6.95mg/L. The pH of water ranged from 5.93 to 8.27 with an average of 7.1. The salinity of the water averaged 0.05 ppt and the total dissolved oxygen averaged 67.25 mg/L. Finally, the water conductivity varied from 91.6-105.2 (µS/cm) with average of 98.4 (µS/cm). The results indicate that the water quality parameters were maintained within the normal range for Nile Tilapia culture.

Table 2: Maximum and minimum values of water parameters and their average variations during the experimental period in the earthen pond with the Hapa net cage system.

	Values		Average
Parameter	Maximum	Minimum	
Temperature (°C)	28.20	21.50	24.85±0.71
Dissolved Oxygen (DO) (mg/L)	8.62	5.28	6.95±0.16
pH	8.27	5.93	7.10±0.10
TDS (mg/L)	69.25	65.25	67.25±3.58
Salinity (ppt)	0.06	0.04	0.05±0.01
Conductivity (µS/cm)	105.20	91.60	98.40±3.57

3.2 Proximate composition of experimental diets

The results for the proximate composition of Nile Tilapia diets used in this experiment are shown in Table 3. An analysis of the data indicated that there was no significant difference ($p<0.05$) between and among the diets implying that the different fish performance criteria can be compared.

Table 3: Proximate composition (% DM) of Nile Tilapia diets

	Treatment group diets				
Parameter	T0	T25	T50	T75	T100
Dry matter	89.80	90.60	89.99	90.54	89.99
Crude protein	23.73	24.72	24.00	24.58	25.25
Ether extract	10.69	10.71	11.22	11.82	12.78
Crude ash	12.36	12.36	12.22	12.37	12.34
Crude Fiber	5.13	5.85	6.33	6.41	7.67

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T0- control (no BSFLM inclusion); T25 - (25% BSFLM), T50 - (50% BSFLM), T75 - (75% BSFLM), and T100 – (full FM substitution).

3.3 Fish growth performance

The results of the growth performance of the Nile Tilapia are presented in Tables 4 and 5. The initial weight and length of the fish at the start of the experiment were similar across the treatment diets. Various growth parameters including weight gain, length gain and other growth parameters throughout the course of the study period have been provided with the most significant results coming from T75 (with 75% inclusion level of BSFL meal), which had a weight of 98.86 g. This was the highest weight average recorded throughout the study period followed by T50 (inclusion level 50% of BSFL meal), which recorded 87.48 g. Treatment T100 had the third highest weight average at 84.16 g followed by T25 at 83.78 g and T0 at 79.91 g. The ranking for average weight gain was from T75 at 64.98 g, T50 at 55.11 g, T25 at 53.44 g, and T100 at 51.16 g with the lowest being recorded from T0 at 49.94 g.

Table 4: Growth performance of Nile Tilapia fed on diets with varying inclusion levels of BSFLM

	Treatment group diets*, ≈					P-Value
Parameter	T0	T25	T50	T75	T100	
Initial Weight	30.42±0.56	30.33±0.43	32.38±1.29	33.88±2.18	33.00±1.81	0.307
Final Weight	79.91±2.16	83.78±2.68	87.48±2.37	98.86±3.35	84.16±2.56	0.484
Weight Gain	49.94±2.06	53.44±2.12	55.11±2.38	64.98±2.88	51.16±2.67	0.279
Average Weight Gain Per Week	$2.47±0.02^{b}$	$2.67±0.03^{ab}$	$2.76±0.02^{b}$	$3.25±0.03^{a}$	$2.55±0.03^{c}$	0.016
SGR	$0.35±0.02^{c}$	$0.42±0.01^{ab}$	$0.44±0.02^{bc}$	$0.52±0.02^{a}$	$0.41±0.01^{c}$	0.002
FCR	$2.26±0.12^{b}$	$2.19±0.09^{c}$	$2.22±0.07^{a}$	$2.13±0.06^{a}$	$2.30±0.07^{a}$	0.008
Conditional factor (K)	$5.00±0.12^{d}$	$5.43±0.21^{c}$	$5.75±0.15^{b}$	$6.33±0.32^{a}$	$5.50±0.22^{bc}$	0.025
Survival Rate	91.67±1.94	90.83±0.91	93.33±2.76	95.83±3.31	95.00±2.94	0.825

*****Means with different superscripts are significantly different at $p < 0.05$. SGR - Specific growth rate. FCR – Feed Conversion Ratio, *See text for description of the treatment group diet

Treatment T75 recorded the highest values across all growth parameters with an SGR of 0.52 and FCR value of 2.13. The treatment with the lowest SGR was T100 at 0.41 and the highest FCR of 2.30. The highest conditional factor was recorded in T75 with a value of 6.33 while it was lowest in T0 at 5.00. The survival rate across the different treatments was significantly different with T75 recording the highest survival rate at 95.83% with T0 recording the lowest at 91.67%.

Similar to the weight growth performance, the length of the Nile Tilapia showed comparable responses to the experimental diets as highlighted in table 5 below. The largest samples in length of the Nile Tilapia came from T75 at 16.40 cm followed by T50 at 16.10 cm, T25 at 16.09 cm, T0 at

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16.02 cm and T100 at 15.78 cm. However, the highest length gain was from T75 at 10.25 cm and the lowest was from T100 at 9.30 cm.

Table 5: Growth Performance of Nile Tilapia fed on diets with varying inclusion of BSFLM

	Treatment group diets*, ≈					P-Value
Parameter∞	T0	T25	T50	T75	T100	
Initial Length	6.23±1.72	6.25±1.53	6.53±2.06	6.70±2.78	6.48±3.06	0.542
Final Length	16.02±3.23	16.09±3.31	16.10±4.26	16.40±4.15	15.78±3.23	0.578
Length Gain	9.79±2.16	9.84±2.21	9.57±2.18	10.25±3.11	9.30±2.13	0.738
ALGW	$0.45±0.02^{c}$	$0.45±0.02^{b}$	$0.44±0.01^{b}$	$0.47±0.02^{a}$	$0.42±0.03^{c}$	0.041
ALGD	$0.06±0.01^{c}$	$0.06±0.01^{b}$	$0.06±0.01^{b}$	$0.07±0.01^{a}$	$0.06±0.01^{c}$	0.006

*See text for description of the treatment group diet, ≈Means with different superscripts are significantly different at $p< 0.05$, ∞ALGW; Average Length Gain Per Week, ALGD; Average Length Gain Per Day

3.4 Carcass composition of Nile Tilapia

Table 6 presents the results of the nutrient composition of Nile Tilapia carcass. Generally, the DM content of the carcass varied across treatments and ranged between 86.56% to 88.80%. Crude protein was highest in T75 at 68.80% and lowest in T0 at 65.70%. The levels of ether extract were higher in T100 at 13.98% and lowest in T25 at 11.20%.

Table 6: The Nutrient Content (% DM) of Nile Tilapia Carcass fed on diets with varying inclusion levels of BSFLM

	Treatment group diets				
Parameter	T0	T25	T50	T75	T100
Dry matter	88.50	88.40	88.30	88.80	86.56
Crude protein	65.70	67.30	68.00	68.80	66.59
Ether extract	11.60	11.20	12.20	13.10	13.98
Crude ash	17.20	18.40	16.20	16.20	15.88

*See text for description of the treatment group diet

Amino acids profile obtained from the carcass is shown in Table 7 with nine essential amino acids being detected from the carcass samples. Its noteworthy that the amino acids content increased with the substitution of BSFLM for FM in the diet of Nile Tilapia.

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Table 7: The amino acid content (% DM) of carcasses of Nile Tilapia fed diets with varying inclusion levels of BSFLM

	Treatment diets				
Parameter	T0	T25	T50	T75	T100
Arginine	4.41	4.56	4.69	6.76	6.34
Threonine	2.93	3.32	3.15	4.53	4.25
Valine	3.41	3.54	3.53	5.28	4.93
Methionine	1.92	2.21	2.54	2.97	2.72
Isoleucine	3.43	3.12	3.13	4.63	4.36
Leucine	5.25	5.37	5.43	7.95	7.45
Phenylalanine	2.85	2.92	2.99	4.31	4.54
Lysine	5.74	5.88	6.54	8.72	8.22
Histidine	1.55	1.66	1.68	2.39	2.20

*See text for description of the treatment group diet

3.5 Cost-benefit analysis.

Table 8 shows the cost-benefit analysis for the study on the substitution of FM with BSFLM at different treatment levels. The gross profit and cost benefit ratio (CBR) were highest in T75 at $0.14 and $2.07 respectively. This was followed by treatment T100 with a profit of $0.12 and a CBR of 1.84. The respective profit and CBR for treatment T50 was at $0.11 and 1.57. The values for profit and CBR were lowest in T25 at $0.06 profit and 1.21. The highest ROI was recorded for treatment T75 at 106.91. It was lowest for treatment T25 at 21.21.

Table 8: Cost–benefit analysis of feeding Nile Tilapia on diets with varying levels of BSFLM

	Treatment group diets*					P-Value
Parameter	T0	T25	T50	T75	T100	
Cost of Feed (USD/kg)	0.32±0.00 ^{a}	0.31±0.00 ^{d}	0.31±0.00 ^{c}	0.29±0.00 ^{e}	0.31 ±0.00 ^{b}	0.000
Total Feed Intake (g/Fish)	98.54±3.76	100.33±4.18	88.80±4.62	87.79±5.17	85.30±3.43	0.324
Cost of Feed Consumed (USD/Fish)	0.28±0.01	0.28±0.01	0.23±0.03	0.21±0.05	0.21±0.04	0.420
Sale (USD)	0.34±0.01	0.34±0.01	0.33±0.01	0.34±0.02	0.33±0.01	0.852
Gross Profit Margin	0.06±0.01	0.13±0.01	0.11±0.02	0.14±0.04	0.12±0.03	0.259
Cost Benefit Ratio (CBR)	1.24±0.06	1.71±0.03	1.57±0.27	2.07±0.60	1.84±0.50	0.430
Return on Investment (RoI) in %	23.85±5.66	71.21±2.94	57.53±27.01	106.91±59.94	83.52±49.71	0.430

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*See text for description of the treatment group diets

4.0 Discussion

The aquaculture industry is expanding fast to meet the increasing demand for high-quality protein to meet the growing global demand. However, there are many constraints that limit the growth of the sector. The main one being high cost of aquafeeds. In many times, the available feeds are of low quality thus negatively impacting the performance of the fish. The feeding costs in aquaculture accounts for over half of the costs of fish production (Limbu, 2020). Feeding is required for the growth, survival and health of fish. To realize profitable and economically sustainable fish production, reduction in costs of feeds is necessary. The cost reduction must not impact the sustainability of aquaculture farming negatively. Furthermore, any proposed feedstuff must not compromise the health, survival and performance of the cultured fish. Traditional protein sources used in aquaculture feed, such as fishmeal, are becoming increasingly scarce and expensive, leading to a need for alternative protein sources (Gasco et al., 2020). The Black Soldier Fly (BSF) larvae as a protein source in Nile Tilapia feed has gained interest due to its nutritional characteristics and sustainability (Muin et al., 2017). Learning about the importance of BSF larvae as a protein source in Nile Tilapia feed is important to support the development of more sustainable and cost-effective feeding practices in the aquaculture industry (Charo-Karisa et al., 2013; Oteri, et al., 2021). Numerous studies have been carried out with different types of fish including juvenile barramundi (*Lates calcarifer*) by Katya et al. (2017), Siberian sturgeon fingerlings by Rawski et al. (2020) and Atlantic salmon postsmolt by Lock et al. (2016). This study was conducted to analyse the growth parameters and economic viability of culturing Nile Tilapia fish using protein ingredients from BSFL meal.

In the current study, the measured water parameters were dissolved oxygen levels, PH, temperature, total dissolved solids (TDS), salinity and water conductivity (Begum et al., 2014; Makori et al., 2017). These parameters formed the basis of the chemical and physical parameters of the water quality, which were all observed to be within range for the effective growth and development of the Nile Tilapia fish in this study. According to Sunny et al. (2017), all water parameters need to be within a specific range for the crucial development of Nile Tilapia in an aquaculture system. Evidently, the water parameters such as temperature, oxygen levels, PH and ammonia and nitrates concentration form a vital element that influences the growth performance and health status of fish (Islam et al., 2018; Essa and Sayed, 2015). The pH values of the water in the ponds in study ranged from 5.93-7.27 which was within the desirable range for Nile Tilapia. Dissolved oxygen is an important parameter in identifying different water masses (Ibrahim and Ramzy, 2013). The current study values for dissolved oxygen ranged between 5.28-7.62 mg/L which is reported (de Holanda Cavalcante et al., 2014) to be within the tolerant range for Nile Tilapia. Water temperature ranged from 20.5˚C to 25.2˚C. In this study, the recorded water temperatures were within the limits permitted for fish growth (Kohinoor, 2000; Bhatnagar and

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Devi, 2013). Conductivity and salinity of the pond water reported from this study were within the permissible limits for production of Nile Tilapia. Results from this study indicated that the total dissolved solids (TDS) in the water ranged from 65.25-69.25 mg/L. Solids such as ammonia, nitrates and nitrites constitute the TDS. Hargreaves and Tucker (2004) noted that feed is the main source of ammonia in the aquaculture systems. From the levels of TDS recorded, it can be concluded that utilizing BSFL meal diets did not result to higher toxic levels of ammonia and nitrites. According to a study by Wang et al. (2017), the inclusion of insect meal, housefly (*Musca domestica*) maggot meal was found to reduce the quality of some water parameters and consequently increased levels of nitrites and total phosphorus.

The results of the current study indicate that the total feed intake was highest in in fish fed diets containing 75% BSFL meal (T75) than any other treatment diet group and lowest in fish fed diets containing 0% BSFL meal (T0). Inclusion of BSFL meal at 100% in the diets resulted to reduction in the feed intake indicating that higher levels, above 75%, depressed intake. A study by Xiao et al. (2018) showed that including BSFL meal at levels above 25% depressed feed intake and growth in Nile Tilapia. This could be attributed to the fact that high inclusion levels of BSFL meal in fish diets reduce feed palatability thus lowering feed consumption (Burr et al., 2012). The presence of the chitin component (anti-nutritive factor) in BSF meal has been reported to be relatively difficult to be broken down by fish (Talamuk, 2016). The progressive increase in levels of BSFL meal shows a declining correlation to feed consumption due to the high chitin component of the BSFL which reduce digestibility and growth performance as seen in other species like Yellow catfish (*Pelteobagrus fulvidraco*) (Xiao et al., 2018) and Jian carp (*Cyprinus carpio var Jian*) (Zhou et al., 2018). This study ensured that the BSF larvae used in the study were harvested at the right stage when chitin constitution was not at maximum explaining the higher inclusion levels without corresponding negative impact on the fish performance.

The present study shows that using 75% FM substitution with BSFL meal provides the highest length and weight gain across the different treatments. This also corresponds with the highest SGR of the treatment in comparison with the others which showed significant differences at $p< 0.05$. Despite treatment T75% having the highest body weight gain compared to all other treatment diets, the body weight gain of the fish among the treatments was not statistically significant ($p>0.05$). Nevertheless, the specific growth rate (SGR) was statistically significant among the treatment diets. The high weight and length gain is attributed to T75 having a low FCR as previously highlighted by Devic et al. (2018). The use of insect meals particularly BSFL meal can be attributed to the increased weight and length gain, which is attributed to the high growth performance as reported by (Basto et al., 2020). This is collaborated by Daliri et al. (2012) who reported a relative increase in weight from the fish fed on diets containing BSFL meal. The increase in body weight was accompanied by an increase in the length of the fish. The findings correspond with the results

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of a study by Limbu et al. (2022) which showed the highest body weight gain coming from fish fed on diets containing 75% BSFL meal. Results from a study by Shati et al. (2022) demonstrated that fish fed on diets in containing BSFL meal had some of the highest body weight gain and specific growth rate. Li et al. (2020) had similar deductions from juvenile grass carp fed on diets containing BSFL meal. Fish diets containing a well-balanced amino acid profile, high digestibility and good palatability show the highest growth performance of fish (Khan, 2018). Contrary to this study findings, Mundida et al. (2023) stated that fish fed on diets containing 0% BSFL meal had the highest recorded body weight gain compared to those on diets supplemented with 25%, 75% and 100% BSFL meal. Talamuk (2016) reported that diets containing 50%, 75% and 100% BSFL meal had reduced body weight gain and specific growth rate of fish. Other authors have also found similar results when showing how the use of BSFL meal in fish diets depressed the body weight gain compared to a control diet (0% BSFL meal) (Devic et al., 2018; Muin et al., 2017; Rana et al., 2015).

Devic et al., (2018), reported that high feed utilization efficiency is correlated to a lower FCR. The lowest FCR from the study was recorded in fish fed diets containing 75% BSFL meal compared to the other treatments diets and the results were significantly different ($p<0.05$). Similarly**,** Limbu et al. (2022) reported the lowest FCR in Nile Tilapia fed diets containing 75% BSFL meal indicating efficient nutrients utilization. Treatment T100 showed the highest FCR. Despite that our results indicate 75% BSFL meal inclusion in Nile Tilapia diets had the lowest FCR than other diets, contrary results have been reported. In their study, Wachira et al. (2021) reported the highest feed conversion ratio in Nile Tilapia fish fed diets containing above 67% BSFL meal. High inclusion levels of insect diets have been found to impair digestibility and reduce nutrients utilization due to the presence of chitin in BSFL meals (Kroeckel et al., 2012). In a study by Mundida et al. (2023) inclusion of 100% BSFL meal in formulation of African Catfish diets resulted to lower FCR compared with other diets. However, results from the study by Xiao et al. (2018) recorded highest FCR when yellow catfish were fed diets containing 100% BSFL meal as a substitute for the conventional protein source. For other fish species including the Siberian sturgeon fingerlings (Rawski et al., 2020) and Atlantic salmon (Lock et al., 2016), utilizing BSFL meal as an alternative protein source has been found to increase FCR due to the presence of high levels of fat content present in the BSFLM. Basto et al. (2020) demonstrated that defatting the BSFL meal resulted in an improved digestibility, lower FCR and increase nutrient utilization in fish.

Survival rate (SR) is a vital parameter in determining production efficiency of Nile Tilapia. Furthermore, it has a direct relationship with the amount of fish produced implying that a higher SR results to more fish being harvested. Different feed rations have different outcomes in terms of SR (Ngugi et al., 2007). Inclusion of BSFL meal in fish diets did not result to negative effect on SR in this study. This concurs with the study by Nairuti et al. (2021). The SR in the present study were highest ($P<0.05$) in Nile Tilapia fish fed diets containing 75% and 100% BSFL meal at 95.83%

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and 95.00% respectively, whereas lower results were observed in diets containing 0%, 25% and 50% BSFL. Our results reiterate that replacing FM with BSFL meal at different inclusion levels influenced the survival rates of Nile Tilapia across all the treatments. However, Limbu et al. (2022) reported differing results that indicate that the inclusion of BSFL meal in formulation of Nile Tilapia diets had no significantly effect on the SR of the fish. Care has to be taken to ensure that indirect effects of feeds (e.g. excessive feed) in the pond does not impact SR. This underlines the progressive monitoring of water parameters in this study. Khan et al. (2016) noted that water quality parameters should be retained within the set standards ensure high survival rates of Nile Tilapia.

Essential amino acids are the most important group of amino acids as they are vital for body tissue elaboration and regeneration (Mariotti, 2016) and they can only be acquired through dietary consumption. The findings of the current study indicate that feeding Nile Tilapia with high levels of BSFL meal increases the concentration of essential nutrients. The overall nutritional analysis of the Nile Tilapia carcasses fed on BSFL meal showed high levels of amino acid content with increasing levels of dietary BSFL meal levels.

Economic returns were affected by the inclusion of BSFL meal in test diets. Profitability increased with inclusion of the meal in the fish diets implying that besides positively impacting growth performance, Nile Tilapia fish production enterprises would economically gain from inclusion of cheaply produced insect meals. Economic sustainability in fish production has previously been highlighted by Limbu (2020). In this study, the economic analysis mainly focused on the return on investment and the cost–benefit ratio. Reducing the costs of operation play a major role in profitability. The low input costs across treatments using BSFL meal highlighted the low cost of input to meet similar nutritional requirements while not affecting the overall performance of the diets. The T75 treatment resulted in the greatest return on investment followed by T100. This is attributed to the low cost of the BSFL meal input and the corresponding fast growth in fish fed on diets that included the meal. This is also documented in the study by Kishawy et al. (2022). The cost-benefit ratio was highest for T100 treatment followed by T75 while it was lowest in treatment group T0. It was notable from this study that the costs of feeds reduced while the gross profit margin gross increased with increasing levels of BSFL meal. Results from previous studies (e.g. Onsongo et al., 2018) have also demonstrated a reduction in the costs of feeds when BSFL meal was used to replace conventional protein sources. In addition, various studies conducted with different fish species including the European sea bass (*Dicentrarchus labrax*) (Abdel-Tawwab et al., 2020), Nile tilapia (Wachira et al., 2021) and Siberian sturgeon (Rawski et al., 2021) have shown that feed costs reduced and net returns increased when BSFL meals were used to replace conventional protein sources. In aquaculture, minimization the costs of feeds as a major expense enhances profitability. This study shows that the use of BSFL meal as an alternative to FM has

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significant economic returns, therefore, showing significant promise in the expansion of the industry.

5.0 Conclusion

This study focused on growth performance and economic viability of rearing Nile Tilapia fed on diets that substituted FM with BSFLM. The findings from the study demonstrated the feasibility of utilizing insect meal BSFLM as a suitable protein source that can be utilized in making of fish diets with no adverse effects on the growth performance as well as the survival of the Nile Tilapia. The growth parameters focused on determining the optimal inclusion levels that did not negatively impact the growth performance. Further, an economic analysis from this study showed that it is possible to use BSFL meal to reduce the cost of aquafeeds which results to an increase in Nile Tilapia enterprise profitability. Performance, survival and economic analysis findings from this study supports an inclusion level of BSFL meal at 75% of the fish meal.

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6.1 Funding

None.

6.2 General acknowledgement

None

6.3 Declaration of interest

None

6.4 Ethical clearance

Ethical clearance under the ethical policies and guidelines from National Commission for Science, Technology and Innovation (NACOSTI) in Kenya were sought and applied from Jomo Kenyatta University Institutional Research and Ethics Review Committee. An approval was granted.

6.5 Conflict of interest

None

6.6 Data availability statement

The authors confirm that the data contained in this article is from our study and it is accessible upon inquiry with the approval of the authors who possess the data.

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