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Growth Performance of African Catfish (*Clarias Gariepinus*) Fed on Diets Containing Black Soldier Fly (*Hermetia Illucens*) Larvae Under Aquaponic System

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Abstract

Cost of fish production can be reduced by replacement of high-priced fishmeal (FM) with insects sourced ingredients. Four months feed experiment was conducted at a fish farm in Baringo County, Kenya to investigate effects of substituting fishmeal (FM) with black soldier fly larvae meal (BSFLM) on survival and growth performance of *C. gariepinus* under aquaponic system. Three test diets 35% crude protein content (CP) in which FM was substituted by BSFLM at 25%, 50% and 75% were formulated and experimented with commercial diet of 35% CP. Four weeks old *C. gariepinus* were stocked in 12 tanks at a density of 50 fish/tank and subjected to the diets. Fish were sampled every three weeks; water parameters were sampled weekly and mortality recorded on occurrence. Diet with 50% BSFLM obtained better FCR for formulated diets with no significance (*P<0.05*) for FCR and survival. Weight gain of control diet (97.07 g) was significant (*P<0.05*) compared to formulated diets 64.09g, 69.78g and 67.77g for 75%, 50% and 25% of BSFL replacement respectively. Growth performance and survival demonstrated that BSFLM has potential to substitute FM up to 75%. The fish productivity can be improved and feed cost reduced by incorporating fully defatted BSFLM with CP higher than 25.3% used for the diets.

Introduction

Globally, aquaculture production is the most immediate solution to declining capture fisheries, however, it also faces a number of challenges that prevent it from reaching its full potential (Barbu *et al.,* 2016). Outdated culture systems and high cost of fish feeds resulting from competition of raw materials have been identified as major setbacks in the growth of aquaculture in most developing countries. Modern aquaculture technologies such as aquaponic system offer an opportunity for exploiting limited land and scarce water to farm fish and crops within the same system (Rurangwa and Verdegem, 2014) thus accelerating productivity. However, this requires innovative approach that use alternative sources of energy such as solar power, thus a shift from the high-cost national gridline electricity (Badiola *et al.,* 2018) characterized by power outrage and high costs per unit of use. Aquaponic system offers an excellent alternative to traditional aquaculture practices that have struggled to intensify productivity. It is characterized by intensive fish production unit using a series of water treatment steps that include plants and filters for removing nutrients and impurities from water to facilitate its reuse (Espinal and Mutalic, 2019). Nile tilapia

(*Oreochromis niloticus)* and African catfish (*Clarias gariepinus)*, are the most cultured species in Africa and have in previous studies demonstrated their candidature in aquaponics system (Ekawati *et al.,* 2021; Love *et al.,* 2015). A variety of plants can be grown within the aquaponic system under the hydroponic unit for nutrients uptake thus maintaining the integrity of water within the system for fish culture. Some of the plants grown under aquaponic systems include; Leafy vegetables (Spinach and Amaranth), Fruit vegetables (Cucumber and Eggplant), Root vegetables (Beets and Radishes) among other plants (Kim 2018).

C. gariepinus preference in aquaculture is as a result of its ability to tolerate high environmental temperatures and low dissolved oxygen thus making it a good candidate for intensive farming, (Safran, 2009). Under best management practices, *C. gariepinus* can be cultured intensively (Somerville *et. al*., 2014) under limited land and water resources (Huntington *et al.,* 2017). Demand for *C. gariepinus,* both for food and as bait in capture fisheries has been increasing substantially in Kenya in the last few years (Omondi *et al*., 2001). Kenya's State Department of Fisheries and the Blue Economy estimates a demand of about 10 million *C. gariepinus* fingerlings per year for aquaculture and 18 million fingerlings per year for Lake Victoria capture fisheries. This adds up to a total demand of about 28 million *C. gariepinus* fingerlings annually, thus informing its selection for this study.

Quality, availability and cost of fish feeds are the most prohibitive aspects in Kenya's aquaculture development (Munguti *et al.,* 2021). Fish feeds are important component in the value chain of *C. gariepinus* production. Substantial percentage of *C. gariepinus* production cost is incurred in procurement of feeds (Adewolu *et al.,* 2010). Commercial feeds are generally expensive and their prices continue to rise due to competition for ingredients by other animal feed manufacturers, (FAO 2014). Complete diets contain plant and animal sourced ingredients that provide all nutritional requirements of fish should be formulated so as to achieve good health and maximum growth of cultured fish (Al Mahmud *et al.,* 2012). To realize economic viability, supply of highly nutritious and low-cost ingredients should be used for formulation (Munguti *et al.,* 2009). Therefore, it is important to replace the commonly used ingredients that are expensive with non-conventional locally available inexpensive ingredients to reduce the cost of fish feeds (Chepkirui *et al.,* 2011; Liti *et al*., 2002).

Fishmeal is a conventional ingredient used for animal feeds formulation (Walker, 2009), with aquaculture industry accounting for 68% of fishmeal consumption in the world (Naylor *et al.,* 2010; Miles and Jacob, 2011). As such, market supply of fish meal is declining and becoming unsustainable due to over exploitation from nature making it very expensive for small scale fish farming (Munguti *et al.,* 2014). Therefore, diversification of protein sourced ingredients for formulating fish feeds will result to significant reduction of the cost of fish production thus encouraging more farmers to take up fish farming (Ngugi *et al.,* 2007). The potential of insect-based ingredients in replacing fishmeal has shown positive results in growth performance on several fish species (Stamer *et al.,* 2014). Thus, insect meals have been incorporated in fish feeds formulation as protein source ingredient. Among the promising insect species for commercial feed formulation include the black soldier fly (BSF), common house fly, silk worms and house cricket (Tilami *et al.,* 2020). Termites and grasshoppers are also viable in animal feeds formulation though to a lesser extent. Recent studies have shown black soldier fly larvae to be a potential protein source and alternative to fish meal (FM) in formulating fish diets (Matteo *et al*., 2020). The BSF larvae can easily be cultured using a variety of organic waste generated within the farm making it an eco-friendly insect and very cheap source of protein, hence a prospective ingredient to reduce production cost (Tran, Gnaedinger and Merlin 2015). Proximate composition of the larvae has shown a higher crude proteins content value of up to 45%, presence of microelements, amino and fatty acids in required quantities essential for fish growth (Xiao *et al.,* 2018). The present study was aimed at formulating three experimental diets that were tested against a commercial diet with percentage proportion of FM and BSFLM in formulated experimental diets gradually being reduced and increased respectively. The four diets were evaluated on survival and growth performance for intensive production of *C. gariepinus* reared under a solar powered aquaponic system.

Materials and Methods

The study was carried-out over four months duration at a private fish farm in Baringo county, Kenya (0°39'N, 36°05'E), within an altitude of 970 meters above sea level, average annual temperature and rainfall is estimated at 33^{o}C and 684mm respectively. Proximate analysis of feed ingredients and formulated diets was conducted at food science laboratory of Jomo Kenyatta University of Agriculture and Technology (JKUAT) while chemical water parameters were analyzed at Kenya Marine and Fisheries Research Institute KMFRI laboratory, Baringo station.

Experimental Design and Set-up

The study was carried out under complete randomized block design using aquaponic system (Figure 1). The system comprised; 12 fish rearing tanks for fish culture, 4 sumps that had submissible water pumps for water recirculation and 4 hydroponic units that were used in growing of spinach (*Spinacea oleracea*) for nutrients uptake from fish rearing water before being recycled to fish rearing tanks.

Sourcing Ingredients, Proximate Analysis and Diet Formulation

Wheat bran (WB), cotton seed cake (CSC) and sunflower seed cake (SSC) were sourced from animal feeds raw material outlet within Nakuru town, partially defatted 2 weeks old BSFL cultured using kitchen waste was sourced from International Centre of Insect Physiology and Ecology (ICIPE) Nairobi while fish meal was obtained from Kendu Bay in Homa Bay County. Proximate composition of individual ingredients and diets were analyzed for dry matter (DM), crude protein (CP), crude fibre (CF) ether extract (EE) and ash content. The analysis was carried out in triplicate using the procedure described in AOAC (2005) and presented as shown in Tables 1 and 3 respectively, while percentage ratio of each ingredient in diets is presented in Table 2. (NFE) was determined by the difference method (DM – CP – EE –CF –Ash). NB: Commercial diet (D_c) 35% CP (control) was sourced from (Unga Farm Care Limited) within Nakuru town.

The ingredients were sun dried, ground and three test diets (D_1, D_2 and D_3) of 35% crude proteins (CP) content were formulated using Pearson Square method by substituting FM with BSFLM in (D_1, D_2 and D_3) at (50-50, 75-25, and 25-75) % ratios respectively. Using water, the formulated diets were made into dough and pelletized through 2 mm dice, then sundried appropriately before being packaged and stored at room temperature in plastic containers.

Stocking and Feeding

Clarias gariepinus fingerlings were obtained from Kenya Marine and Fisheries Research Institute, Sagana Aquaculture Research Center located in Central Kenya. Since aquaponics entails an intensive culture system, small area is used to culture a higher number of fish. A total of 50 *C. gariepinus* fingerlings weighing (5 ± 0.5g) were acclimatized for a week and thereafter stocked in 12 (1000 litre) tanks at a stocking density of 0.05 fish/litre of water. The three test diets and control diet (D_1, D_2, D_3 and D_c) were randomly allocated to the first four set of tanks and replicated thrice. Cover nets were placed over the tanks to control predators. Fish were hand fed twice daily at 09:30hrs and 15:30hrs at 5% and 3% body weight for the first two and the last two months of the trials respectively.

Fish Sampling and Growth Determination

20 litres buckets were halfway filled with 10 litres of water in which fish were placed after being removed from fish rearing tanks using a scope net. Length was determined using a metre rule bound on a board while weight was determined using weighing machine, WTC 2000. Sampling of fish was done after every three weeks to monitor growth of fish that was used to adjust the feeding rate.

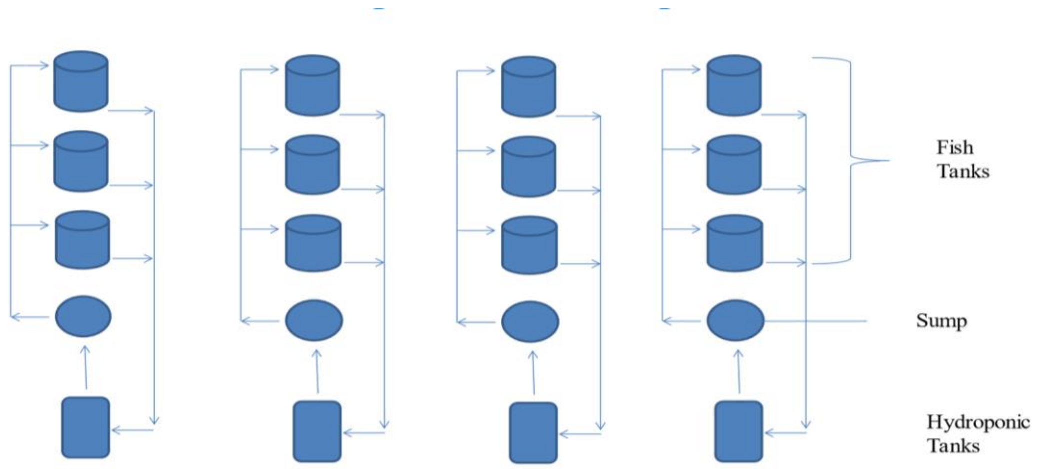

Figure 1. The experimental aquaponic system (Not drawn to scale). The arrows indicate the direction of flow of water within the system.

Table 1. Percentage (%) proximate composition of analyzed ingredients used in diet formulation

Parameter	DM	CP	EE	CF	Ash	NFE
BSFL	95.8	25.3	27.3	8.0	14.7	20.5
FM	89.94	48.80	12.4	1.28	9.28	18.18
CSC	92.14	32.29	8.60	6.46	18.54	26.25
SSC	91.85	26.83	9.90	16.92	9.44	28.76
WB	90.08	17.10	5.01	10.96	8.43	48.58

DM: Dry matter, CP: Crude proteins, EE: Ether extract, Crude fibre: NFE: Nitrogen free extract.
BSF: Black soldier fly larvae, FM: Fishmeal, CSC: Cotton seed cake, SSC: Sunflower seed cake and WB: Wheat bran

Water Quality Analysis

Specified water quality parameters (dissolved oxygen, temperature, pH, conductivity and total dissolved substance) were monitored after every week at 07:00hrs using a multiparameter water quality meter (YSI) while water samples were collected in 200ml sample collection bottles and taken to the laboratory to determine the levels of ammonia, phosphorous, nitrites and nitrates using UV Shimadzu spectrometer (UV-1800).

Evaluation of Survival and Dietary Performance

At the end of the experiment, fish were harvested, counted, weight and length documented. Survival, Growth and feed efficiency were evaluated by the following standard formula.

Survival rate (SR) (%) = 100 X (Final number of fish) / (Initial number of fish)

Daily growth (DG) (g) = Final weight/Time (Exp days)

Body weight gain (BWG) (g) = Final weight – Initial weight

Specific Growth Rate (SGR) (%) = 100% X [(In Final weight (g) – In Initial weight (g)) / Time (Exp days)]

Fish Food Conversion Ratio (FCR) = Feed provided (g) / Weight gain (g)

Data Analysis

Data storage and management was done using Microsoft Excel spreadsheet for windows 2010 while analysis was done using SPSS Version 23.0 for windows. Means for growth and water quality parameters for all the treatments were compared using Analysis of Variance (ANOVA). Significant difference for all inference tests were separated using the Tukey-HSD post hoc, at 0.05 level of significance. The data was presented using tables and a graph plotted using excel spreadsheet.

Results

Fish Survival, Feed Utilization and Growth Parameters

Survival of fish under the set growth conditions and experimental diets was above 95% with relatively low mortality rate experienced in the first week of stocking especially for fish cultured under diet 3 (D3) (Table 4). There was no significant difference ($P<0.05$) observed in survival rate (SR) among all the dietary treatment and control diet under the present study. Fish that were fed on diets that BSFLM substituted FM had statistically

Table 2. Percentage (%) crude proteins content, composition of ingredients and essential amino acids in test diets containing varying inclusion of BSFL in partial substitution of FM

		Experimental diets			
Parameter	Unit	D_1	D_2	D_3	D_c
Proteins analysis					
Crude proteins	(g $100g^{-1}$)	35.0	35.0	35.0	35.0
Ingredients					
BSFL	(g 100g-1)	13.75	6.875	20.625	-
FM	(g 100g-1)	13.75	20.625	6.875	5.7
Soybean meal	(g 100g-1)	-	-	-	25.05
Cotton seed cake	(g 100g-1)	16.27	16.27	16.27	-
Sunflower seed cake	(g 100g-1)	25.495	25.495	25.495	-
Wheat bran	(g 100g-1)	30.735	30.735	30.735	68.15
Essential amino acids					
Methionine	(g 100g-1)	-	-	-	0.5
Lysine	(g 100g-1)	-	-	-	0.2
Choline	(g 100g-1)	-	-	-	0.4

D_1 =Diet 1, D_2 =Diet 2, D_3 =Diet 3 and D_c =Control diet

Table 3. Proximate composition of formulated test diets containing different percentages of BSFL as a substitution of FM

		Means ± SD			
Parameter	Unit	D_1	D_2	D_3	D_c
Dry matter	(g/100g)	91.43±0.81a	91.57±0.35a	91.57±0.09a	91.55±0.63a
Crude proteins	(g/100g)	35.39±0.07a	35.28±0.10a	35.30±0.02a	35.41±0.19a
Ether extract	(g/100g)	9.09±0.14b	10.28±0.10c	11.47±0.93d	7.25±0.32a
Ash	(g/100g)	10.65±0.05b	10.05±0.06b	6.65±0.08a	10.31±0.06b
Crude fiber	(g/100g)	5.36±0.39a	6.20±0.52b	6.54±0.18b	6.75±0.25b
Moisture	(g/100g)	8.57±0.86ab	8.42±0.35a	8.57±0.02ab	8.45±0.07a
NFE	(g/100g)	36.28±0.26b	35.95±0.52a	38.00±0.04c	39.56±0.50d

D_1 =Diet 1, D_2 =Diet 2, D_3 =Diet 3, D_c =Control diet, and NFE: Nitrogen free extract
a<b<c<d at ($P<0.05$)

similar (*P<0.05*) means in growth weight, daily growth rate and specific growth rate. However, fish that were fed on experimental diets exhibited a relative higher feed conversion ratio (FCR) compared to fish that were fed on control (commercial diet) (table 4). FCR did not differ significantly (*P<0.05*) among the diets that BSFLM substituted FM but was poor than the value recorded for fish fed on the control.

Experimental fish growth curves were exponential for the first five weeks of culture where fish growth assumed more or less linear trends for all the dietary treatments (Figure 2). Differential growth trends exhibited by experimental fish among dietary treatment occurred between weeks five and seven of culture. During the period of week five and seven, the growth curve of fish fed on control diet separated from the growth curves of fish fed on diets that BSFLM substituted FM (Figure 1). Growth appeared to slow down towards the end of the study period for fish subjected to control diet. The growth curves of the test diets had not separated much from each other is the reason of no statistical significance (*P<0.05*) observed for the diets. However, growth of fish fed on test diets appeared to rise exponentially towards the end of the culture period.

Water Quality Parameters

The experimental diets disturbed the water quality parameters contributing to marked significant difference (*P<0.05*) observed for dissolved oxygen (DO) and temperature between treatments (Table 5). However, pH, conductivity and total dissolved substance did not differ statistically (P<0.05) between the treatments. There was no significant difference (*P<0.05*) among water nutrients analyzed (table 5) except for phosphates that showed significant difference (*P<0.05*) between dietary treatments during the culture period (table 5).

Discussion

Presently, feeds nutritionists consider not only feed ingredients nutritional value but also price, availability on demand and sustainability for future use (Devic *et al.,* 2017). Constrains such as high cost, poor quality and unsustainable availability has forced feeds manufacturers to find alternative cost-efficient feeds ingredients to replace the more costly and commonly used FM (Gabriel *et al*., 2007 and Liti *et al* 2005). Studies have shown insects proteins sources, e.g., BSFLM can be

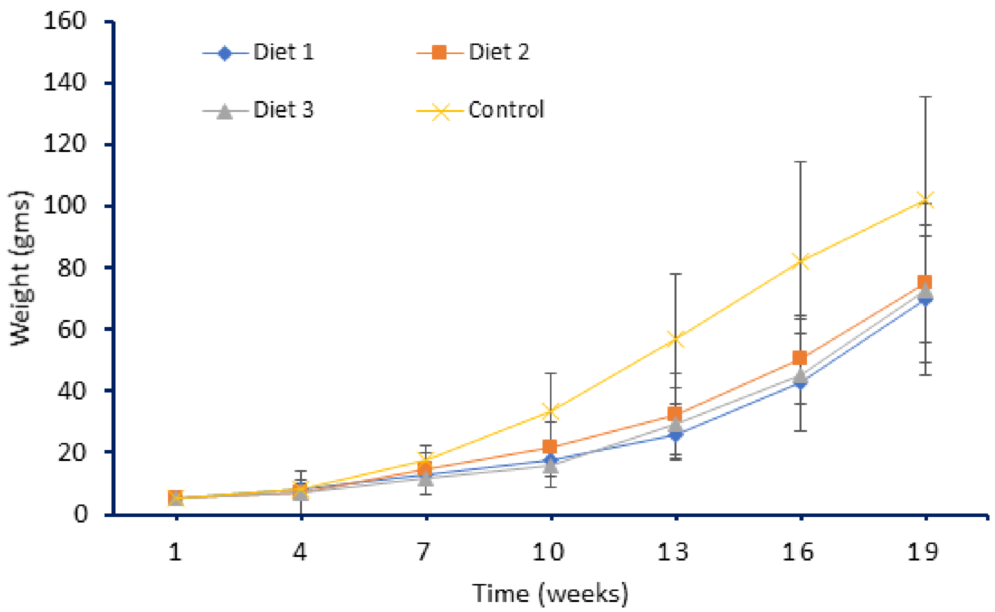

Figure 2. Growth curves for *C. gariepinus* under different BFSL dietary treatments (Diet 1; 50%) (Diet 2; 25%; (Diet 3; 75%) and (Diet 4; control) without BSFL

Table 4. Growth performance of *C. gariepinus* fed on diets containing varying percentages of BSFL and control diet.

			Means ± SD				
BSFL (%)	IW (g)	FW (g)	WG (g)	DGR	SGR	FCR	SR (%)
D1(50%)	5.1±0.00a	69.78±1.57a	64.09±1.57a	0.534±0.01a	2.17±0.01a	1.3±0.02a	100±0.00a
D2(25%)	5.1±0.00a	74.78±1.14b	69.78±1.14b	0.582±0.01a	2.24±0.15a	1.2±0.01a	100±0.00a
D3(75%)	5.1±0.00a	72.87±2.13b	67.77±2.13b	0.565±0.02a	2.22±0.02a	1.3±0.03a	98±0.57a
Dc (0%)	5.1±0.00a	102.17±1.41c	97.07±1.41c	0.809±0.02b	2.50±0.06a	1.1±0.01a	100±0.00a

IW: Initial weight, FW: Final weight, WG: Weight gain, DGR: SGR: Specific growth rate, Daily growth rate, FCR: Food conversion ratio, SR: Survival rate, D_1 =Diet 1, D_2 =Diet 2, D_3 =Diet 3 and D_c =Control diet; a<b<c<d at (P<0.05) used as substitute to FM in aquaculture industry (Xiao *et al.,* 2018). However, dietary substitution of FM with BSFLM in aquafeeds remains controversial due to varying insects' nutritional quality, difference in diet formulation and fish species used in experiments (Matteo *et al.,* 2020. Substrates influence nutritional quality of BSFL biomass as a number of studies have demonstrated remarkable improvement when using substrates containing right polyunsaturated fatty acids (PUFAs) (Barrosso *et al.,* 2017) as BSFL culture media. The crude protein percentage for BSFLM used for the present study was 25.3 % which is substantially lower compared to; (44.86-45.20) % used in trials for Rainbow trout (*Oncorhynchus mykiss*) by (Renna *et al.,* 2017), 41.74% reported by (Muin *et al.,* 2017) used in tilapia (*Oreochromis niloticus*) and 40% reported by (Newton *et al.,* 2005; Sheppard *et al.,* 1994) used in management of swine manure. According to (Barragan-Fonseca *et al* 2017), crude protein content of BSFL decreases as age increases with highest percentage recorded for 5 days old larvae while the least percentage recorded for 20 days old larvae. As such, variation occurs in nutrients composition in the body of BSFL throughout the duration of larval development (Barragan-Fonseca *et al* 2017) affecting growth rates of recipient organism e.g., fish when incorporated in diets depending on the stage of development. FCR is an important tool to determine efficiency, suitability and acceptability of formulated diets for fish (Nadaf *et al.,* 2010). Under optimal environmental condition and best pond management practices, high fish growth rate is achieved (USAID 2011) thus, better FCR. Other factors that influence FCR are type of fish; species and health status that contribute to variation in FCR. Under the current study, FCR of between 1.1 – 1.3 obtained among test diets were lower than FCR values obtained by (Tiamiyu *et al.,* 2017 and Amisah *et al.,* 2009) who tested *C. gariepinus* performance with *Allium sativum,* and *Leucaena leucocephala* replacement reported FCR values ranging between 5.71 – 6.32 and 4.95 – 6.39 respectively. The difference in FCR observed in various studies aforementioned may be attributed to feed ingredients variation, culture systems and varying stocking densities. The FCR under this study for *C. gariepinus* fed on 50% FM replacement indicate better growth performance compared to 25% and 75% FM replacement diets. Similar results were reported by (Muin *et al.,* 2017) for Nile tilapia fingerlings fed on diet containing 50% FM replacement with FCR of 1.91. In another study by (St-Hilaire *et al.,* 2007), better growth performance with favorable FCR was reported on rainbow trout fed on 25% FM replacement diet. This can be explained by (Koprucu and Ozdemir 2005), who reported that BSFL contain chitin made of insoluble fiber that make digestion difficult for diets with high BSFL percentage hence affecting growth performance.

In this study, fish appeared healthy and there was no diseases outbreak throughout the trial period. All diets used for the trials were accepted by *C. gariepinus* irrespective of the percentage BSFL used in the substitution of FM paralleling reports by (Fawole *et al.,* 2019 and Adewolu *et al.,* 2010). The single mortality observed under the current study may have not been diet related but due to mishandling during sampling time thus, a higher survival rate (SR) was reported among the trial diets. The SR observed for this study was higher than that reported by (Nairuti *et al* 2021) on *O. niloticus* but was similar to SR obtained by (Maina *et al* 2020) on *C. gariepinus* under semi-intensive culture systems. Feed acceptance by experimental fish and good water quality parameters that were within the recommended range for fish culture (Tucker and Robinson 1990) may have contributed to the high SR mean. Uniform growth was observed irrespective of test diets subjected on experimental fish during the first three weeks of trials as shown in figure 1. The uniformity in growth may have been attributed to time taken for re-adjustment in digestion and nutrients uptake from experimental diets by *C. gariepinus* that were initially fed with wheat bran for a week before the trials. In support to our finding, (Kumar *et al.,* 2018) reported that the assimilation process of the digestive tract may be stimulated or impaired and therefore affect digestion on sudden change of diet and feeding regime in fish. It is during the initial stage of study that the slowest growth rates in *C. gariepinus* were observed in the entire trial duration. The trends observed during the initial stage of study were also obtained by (Maina *et al* 2015) on *C. gariepinus* fingerlings subjected to diets containing 41% CP under the same FM replacement ratios as used

Table 5. Water quality parameters in tanks under different dietary treatments

		Means ± SD			
Parameter	Unit	D_1	D_2	D_3	D_c
DO	(mgL^{-1})	3.03 ± 0.9^a	3.89 ± 0.74^c	3.66 ± 0.82^b	3.96 ± 0.46^d
Temperature	(^oC)	24.53 ± 1.1^a	25.22 ± 1.27^b	25.98 ± 1.24^b	26.52 ± 1.65^c
pH		7.72 ± 0.52^b	7.72 ± 0.36^b	7.69 ± 0.54^a	7.72 ± 0.52^b
Conductivity	(μScm^{-1})	47.43 ± 3.39^b	45.9 ± 3.93^a	46.76 ± 3.45^b	46.81 ± 3.86^b
TDS	(mgL^{-1})	23.71 ± 1.89^b	22.86 ± 1.9^a	23.29 ±1.68b	32.3 ± 2.02^c
Ammonia	(mgL^{-1})	0.54 ± 0.51^a	0.61 ± 0.59^b	0.48 ± 0.46^a	0.71 ± 0.73^b
Nitrites	(mgL^{-1})	0.24 ± 0.15^a	0.22 ± 0.13^a	0.21 ± 0.12^a	0.30 ± 0.16^b
Nitrates	(mgL^{-1})	1.31 ± 0.78^b	1.0 ± 0.89^a	1.0 ± 0.92^a	1.16 ± 0.99^a
Phosphates	(mgL^{-1})	0.61 ± 0.07^c	0.52 ± 0.04^b	0.51 ± 0.1^b	0.47 ± 0.07^a

D_1, Diet 1; D_2, Diet 2; D_3, Diet 3; D_c Control Diet; DO, Dissolved oxygen; TDS; Total dissolved substance; $a<b<c<d$

in this study. Thereafter, growth curves of fish fed on control and diet containing (25%) BSFL separated from growth curves of fish fed on diets containing (50% and 75%) BSFL. The separation of the curves was a clear demonstration of better growth rates for control and 25% BSFL diets. However, control diet had the highest growth rate on fish as shown in figure 1 compared to the other test diets from the third week to the end of the trials. The trend observed for the control diet was also observed for 25% BSFL diet which was second in growth rate although not significantly different (P>0.05) compared to fish fed on (50% and 75%) BSFL test diets.

Fish fed on 50% BSFL had a better growth rate between week five and week eleven compared to fish fed on 75% BSFL which had the least growth rate for the first eleven weeks of the diets trial. After the eleventh week, the growth rate of 75% BSFL diet improved compared to 50% BSFL thus suggesting better growth performance as fish age on subjection of higher percentage of BSFL formulated diets. Final weight gain by fish fed on 50% BSFL diet was higher than fish fed on 75% BSFL diet paralleling results reported by (Steffens 2007 and Goda *et al.,* 2007) on rainbow trout and *C. gariepinus* having replaced FM by poultry by-products and insect meals respectively at 50% ratio. For present study, BSFL test diets were not supplemented with vitamins nor mineral premix that are essential for early-stage of fish development thus slow growth rate observed at the onset of the study. The slow growth rate observed at fingerling stage may be hasten by inclusion of necessary supplements which are either unavailable or are deficient in BSFL that was used in the feed trials. In intensive culture system where fish depend entirely on formulated feeds, the need for nutrients supplementation has been observed to increase with the variation between the standing fish biomass (De Silva 1992) and that of formulated food. Though the weight gains of fish fed on control diet was higher than for fish fed on BSFL diets, BSFL diets showed steady increase while control diet showed gradual slowing down in fish growth towards the end of the study. Therefore, BSFL formulated diets may outperform the control diet given more experimental time so long as the trends of curves towards the close of the trial are maintained. The weight gains of fish reported for feed trial under the present study shows that diets in which BSFL substituted FM obtained similar growth. The substitution percentages used in the present studies were similar to those used by (Fawole *et al.,* 2019 and Adeworu *et al.,* 2010) with results from both trial indicating BSFL can replace FM up to 75% without impairing and affecting performance in growth and survival of *C. gariepinus*.

Conclusion and Recommendation

This study established that dietary FM can be substituted by partially defatted BSFL ingredient of 25.3% CP at (25, 50 and 75) % rates without; variation in growth performance and negatively affecting survival of *C. gariepinus* reared under aquaponic system. Thus, feed cost can substantially be reduced and profit margin increased by substituting dietary FM up to 75% for economic benefit in *C. gariepinus* production. Better growth rates for increased *C. gariepinus* productivity under aquaponic production system may be obtained by substitution of dietary FM using fully defatted BSFL with higher CP value above the 25.3 % used for the present study.

Ethical Statement

This study was carried out in accordance with the international, national and institutional guidelines for the care of experimental animals. No surgery was performed on the experimental organisms.

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Author Contribution

Conceptualization, B.M., R.K., K.O. and P.O.; Methodology B.M., R.K., K.O., P.O and J.M.; Investigation, B.M.; Formal analysis, B.M., R.K., K.O., P.O., J.M. and E.O.; Writing original draft, B.M.; Writing-reviewing and editing, B.M., R.K., K.O., P.O., J.M. and E.O.; Supervision, R.K., K.O. and P.O.; Project administration, KCSAP; Funding acquisition, B.M.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional or non-professional conflict that would have appeared to influence the work reported in this paper.

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