GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF THE AFRICAN CATFISH (*CLARIAS GARIEPINUS)* REARED ON DIETS CONTAINING BLACK SOLDIER FLY (*HERMETIA ILLUCENS*) LARVAE MEAL

ANDERSON NJOROGE MAINA

A150/OL/CTY/33423/2015

A Thesis Submitted In Partial Fulfillment of the Requirements for the Degree of Master of Science (Animal Nutrition and Management) in the School of Agriculture and Enterprise Development of Kenyatta University

MARCH, 2020

DECLARATION

DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other university or any other award.

Signature................................ Date: 20/3/2020

Anderson Njoroge Maina

Department of Animal Science

SUPERVISORS

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors.

Signature................................ Date 28/3/2020

Dr. Isaac M. Osuga, Ph.D.

Department of Animal Science, Jomo Kenyatta University of Agriculture and Technology

Signature................................ Date 25/3/2020

Dr. Leonard K. Munga, Ph.D.

Department of Animal Sciences, Kenyatta University

Signature .... Date 25/03/2020

Dr. Jonathan M. Munguti, Ph.D.

Kenya Marine and Fisheries Research Institute, Sagana Research Center

DEDICATION

To my dearly beloved wife, Grace Wanjiru Njoroge and Our children, Benedict Maina and Joannah Muthoni "Dear Ones, may you have courage for the great sorrows of life and patience for the small ones; and when you have laboriously accomplished your daily task, go to sleep in peace. God is awake" (Victor Hugo)

ACKNOWLEDGEMENT

God has been merciful to me in ways I cannot comprehend or understand and I am very thankful to Him for his abundant love and mercy. I sincerely thank my supervisors, Dr. Isaac M. Osuga, Dr. Leonard K. Munga and Dr. Jonathan M. Munguti whose guidance in research and preparation of this thesis was valuable. I am immensely thankful to The Netherlands Organization for Scientific Research (NWO) for the funding of this study via the project; Improving Livelihood by Increasing Livestock Production in Africa (ILIPA) as well as ICIPE for facilitating this study.

A lot of gratitude to the KMFRI staff at Sagana, led by Dr. Jonathan M. Munguti, Peter Miruka, Jane Fonda Awuor, Oketch Otama, Elijah Gichana and Nathan Okworo for their immense assistance during the entire period of data collection. I am immensely grateful to ICIPE staff led by Dr. Chrysantus M. Tanga and Yisa Njowe Kieran Bong (a PhD candidate at ICIPE) who guided me gently through with feed and food analysis and for their invaluable guidance in the success of this study.

I also thank my wife Mrs. Grace Wanjiru Njoroge for her prayers and patience throughout the busy schedule.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

ADGW	-	Average daily gain of weight
ADGL	-	Average daily gain of length
BSF	-	Black soldier fly
BSFL	-	Black soldier fly larvae
CP	-	Crude protein
EAA	-	Essential Amino Acids
EE	-	Ether Extracts
FCR	-	Feed conversion ratio
HFMM	-	House fly maggot meal
ICIPE	-	International Center of Insect Physiology and Ecology
KMFRI	-	Kenya Marine and Fisheries Research Institute
LC-MS	-	Liquid chromatography–mass spectrometry
ME	-	Metabolizable Energy
SGR	-	specific growth rate
WHO	-	World Health Organization

ABSTRACT

Fish feed protein ingredients are the most expensive and often unavailable in sub-Saharan Africa especially in commercial aquaculture systems. The major fish feed protein ingredient in fish farming in Kenya is fishmeal (FM) that is often times expensive and adulterated leading to low productivity of fish farming. This problem has necessitated a need for exploring alternative less expensive and easily available protein sources such as black soldier fly larvae (BSFL). This study aimed at evaluating the growth rate, feed utilization, survivability and carcass characteristics of the African catfish (*Clarias gariepinus*) reared on diets containing BSFL meal as a replacement for FM. Treatment diets were formulated for BSFL meal to replace FM at the rate of 0% (C), 25% (D1), 50% (D2), 75% (D3), 100% (D4) and D5 (49% BSFLM, 49% FM and 2% Baker's yeast). All diets were formulated to meet the nutritional requirements of catfish. The catfish were housed in harper nets each measuring 2 by 2 by 2 meters and the net had one millimeter perforations to allow proper circulation of water and also prevent escape of the catfish. Each harper net held 20 pieces of catfish. The experiment was laid out in a completely randomized design with each treatment being replicated three times. The performance of the catfish was determined by recording the weights, lengths and mortality biweekly for six months. Analysis of variance was carried to determine the effects of the treatment diets on the weight gain, length gain and carcasses charateristics. Water quality parameters including dissolved oxygen, temperature, salinity and conductivity measured were within the optimum levels recommended for rearing the African catfish. Catfish consuming diets with 50% and 75% BSF larvae meal had the highest growth rates of 1.01g/day and 0.98g/day respectively. However, the growth rates of the catfish consuming the diets with 0% and 100 % BSFL meal as well as the diet containing 2 % baker's yeast were not significantly different ($P>0.05$). Mortality of 1.10% was noted in the catfish consuming the control diet and diet containing 25 % BSFL but there was no mortality for the other treatment groups. Carcasses of African catfish fed treatment diets with BSFL meal had significantly ($P<0.05$) higher amounts of crude protein (CP) especially for D2 and D3. Ether extracts from the carcasses showed that an increase in BSFL meal led to an increase in the lipid content of the carcasses. The inclusion of BSFL meal did not negatively affect the nutritive composition and carcass quality (especially essential amino acids) of the African catfish. The study noted that the concentration of essential amino acids increased as the amount of BSFL meal in the diets increased. Substitution of BSFL meal for FM in the treatment diets didn't negatively affect the survival rates of the catfish. The study recommends the use of BSFL meal at substitution rates of 50% and 75% for better survival and enhanced growth performance of African catfish as well enhanced quality of its carcass.

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

There has been a marked increase in consumption of animal products, including aquaculture products across the globe due to increased urbanization and improved per capital incomes (Delgado et al., 2003; Steinfeld et al., 2006; Alexandratos and Bruinsma, 2012; United Nations, 2013; Tran et al., 2015). Fish farming is currently the exponentially growing food producing frontier and it has been growing at 8.6% per annum especially in the last few decades (Ahmed and Diana, 2016). Fish feed ingredients have mainly been constituted by use of fishmeal and other aquaculture by-products as the main protein sources (Médale et al., 2013; Soliman et al., 2017).

Fishmeal is considered as a viable source for amino acids and protein while fishery products such as fats provide polyunsaturated fatty acids such omega-3 fatty acids are desirable for their excellent antioxidant properties in human and animal nutrition (Olsen and Hasan, 2012). Availability of fish and fish by-products used for livestock feed must grow by approximately 70% by 2050 in order to meet the increasing demand, with other livestock by products expected to increase by two-fold (IFIF, 2014; FAO, 2014).

Fishmeal has become not only expensive, but its production has been decreasing rapidly due to tighter controls on marine fishing that are meant to control unregulated fishing and over exploitation of pelagic species (FAO, 2012; Shitote et al., 2012). There is therefore an urgent need to explore alternative protein feed sources. Insect meals and whole insect diets have been utilized in fish rearing and livestock nutrition (FAO, 2012; Van Huis., 2013; Van Huis et al., 2013; Cohen, 2015) and there is a need to upscale their use in livestock nutrition (Veldkamp et al., 2012; Henry et al., 2015; Kelemu et al., 2015; Tomberlin et al., 2015; Zieli´nska et al., 2015; Lock et al., 2018; Cappellozza et al., 2019).

Several studies have successfully utilized insect meals in rearing and feeding different livestock and fish species (Smetana et al., 2016). For example Nile Tilapia (*Oreochromis niloticus*) was successfully reared on black soldier fly larvae (BSFL) meal and house fly maggot meal (HFMM) (Bondari and Sheppard, 1981; Ogunji et al., 2008), while African Sharptooth catfish (*Clarias gariepinus*) was reared on HFMM (Aniebo et al., 2009; Idowu and Afolayan, 2013). Similarly turkey birds were reared on HFMM (Zuidhof et al., 2003) and commercial broiler and layer birds reared on BSFL meal (Leiber et al., 2015; Schiavone et al., 2017; Mwaniki et al., 2018; Onsongo et al., 2018) and HFMM (Agunbiade et al., 2007). The European Union as well as the North American countries have already approved use of BSF larvae as animal protein (Commission Regulation (EU), 2017; Sogari et al., 2019). Therefore, the objective of the present study was to evaluate BSF larvae meal as a potential replacement protein ingredient in place of fishmeal in the rearing of the African catfish.

1.2 Statement of the Problem

Protein especially from fishmeal is key component in fish feed diets yet it is the most expensive of all ingredients (Helfrich and Steven, 2002; Muzinic et al., 2006; Soliman et al., 2017). The retailing price of fishmeal in Kenya has been US$ 1.4/kg in 2015 (Fiaboe and Nakimbugwe, 2017). Fishmeal has been the most commonly used ingredient due to its good amino acid content profile and good digestibility. Unfortunately, fishmeal is relatively expensive and indications are that it will be even more expensive in the future (Delgado et al., 2003; Kristofersson and Anderson, 2006; Tacon and Metian, 2008; Rana et al., 2009; Tacon and Metian, 2009). Black soldier fly larvae meal production in houses measuring 5m x10m can produce 2 tonnes of fresh larvae, with a production cost of US$ 0.20/kg DM and being sold to farmers and feed processing companies at US$ 0.90/kg DM (Fiaboe and Nakimbugwe, 2017). Thus, the present study evaluated the potential of BSFL meal as an alternative protein source for the aquaculture systems with a particular reference to the African catfish.

1.3 Justification

There is an urgent need for a high quality feed for aquaculture system in the tropics; in particular to cater for the nutritional requirements for increased production of farmed African Catfish. The nutritional quality of locally produced BSFL is favorable and various studies have found that it can be used to formulate commercial fish feeds while replacing conventional fish feed ingredients such as fishmeal (Ramachandran and Ray, 2007; Rumpold and Schlüter, 2013). Thus, BSF larvae meal is an excellent protein source for different livestock species as shown in previous studies such as Channel catfish (*Ictalurus punctatus*), rainbow trout (*Oncorhynchus mykiss*) and in Turbot (*Scophthalmus maximus*) (St-Hilaire et al., 2007a; Kroeckel et al., 2012), broiler chicken (Schiavone et al., 2017; Onsongo et al., 2018), layer chicken (Mwaniki et al., 2018), white shrimps (Cummins et al., 2017) and Channel cat with tilapia (Bondari and Sheppard, 1987). The African catfish is a common species in the tropical water bodies of Africa and is a key fish species in Kenya commercial aquaculture systems and is especially favored for its dressing and filleting percentage during processing and marketing (FAO, 2006).

1.4 Objective of the Study

1.4.1 Broad Objective

The purpose of the study was to increase African Catfish growth performance and carcass quality characteristics through the utilization of Black Soldier Fly larvae meals.

1.4.2 Specific Objectives

i. To evaluate the growth performance and survival rates of African Catfish fed on Black Soldier Fly larvae-based diets,

ii. To determine the carcass characteristics of African Catfish fed on Black Soldier Fly Larvae.

1.5 Research Questions

i. What is the growth performance of African Catfish raised on BSF larvae meals as dietary replacement for fish meal?

ii. What is the effect of use of BSF larvae meal in African Catfish diet affect the quality of the carcass?

1.6 Conceptual Framework

Production and procurement of quality yet cheap African catfish feeds in this case BSF larvae meals will enhance growth rates, weight gain and quality of catfish reared. Therefore more output and subsequent sales of the produce will lead to an overall increased wellbeing of the population, poverty reduction and improved nutrition.

Independent variables

i. Feeding management (protein sources: fishmeal and BSF larvae meals; crude fat sources: fishmeal and BSF larvae meal; metabolisable energy; vitamin mineral premix and feeding rates at 8% of the body weight for rearing grower catfish)

ii. Water quality characteristics such as pH, dissolved oxygen, temperature and salinity.

iii. Fish genetic characteristics: African catfish

→

Dependent variables

i. Growth rates (Weight gain, length gain, feed conversion efficiency and specific growth rates per day)

ii. Improved fish quality (fish carcass quality: crude protein, ash, ether extracts and protein quality: essential amino acid)

Figure 1.1: Conceptual framework

CHAPTER 2: LITERATURE REVIEW

2.1 The African Catfish

The African catfish (*Clarias gariepinus*) is distributed throughout Africa and it's a very important species of fish especially in capture fisheries and for rearing by fish farmers (FAO year book, 2008; Ponzoni and Nguyen, 2008). This species of fish is found in almost all water bodies including swamps, seasonal pools, seasonal rivers and lakes (Akinsanya and Otubanjo, 2006; Froese and Pauly, 2016; Weyl et al., 2016). Its wide distribution is due to its ability to use atmospheric air and tolerance to low dissolved oxygen (DO) (Nelson, 2006). Burrowing in the mud enables catfish to survive for long periods without water (Skelton, 2001). The African Catfish is also able to feed on a diverse diet (Keyombe et al., 2015); and usually breeds depending on the rainfall patterns. These characteristics of the African catfish have made it resilient in comparison to other species of fish when in prohibitive environs that are affected low dissolved oxygen.

Figure 2.1: Post fingerling African catfish

Various studies have found that the African catfish mature between 30-50cm total lengths (Keyombe et al., 2015). This species of fish is primarily omnivorous (Keyombe et al., 2015) and usually feeds on insects, smaller fish species and young fishes, mollusks and soft plants that thrive in the water bodies (Dadebo et al., 2014). African catfish fingerlings and growers feed on insect larvae, aquatic insects and seed shrimps (Dadebo et al., 2014).

Figure 2.2: Mature African catfish harvested for sale

The African Catfish production in sub-Saharan African is mostly a small scale semi intensive venture among rural farmers (FAO, 2007b; Ngugi et al., 2007) and is usually carried out as a polyculture with the Nile tilapia. Monoculture of this species is carried out but its productivity is highly dependent on quality of the feed (Ogello and Opiyo, 2011). The fish species is well distributed across the world for aquaculture purposes (Na-Nakorn and Brummett, 2009). According to FAO (2020), approximately 230,000 tons of the African catfish were reared and harvested worldwide with Nigeria, Netherlands, Hungary and Kenya been the top producers.

2.2 The black solder fly

Black soldier fly (*Hermetia illucens*) insects belong to the Order Diptera and Family Stratiomyidae (Liu et al., 2017; Nguyen et al., 2015). They are native species in Kenya and regularly occur around the fecal waste piles of poultry, swine and other livestock such as cattle, sheep and goats (Chia et al., 2018) and can be reared on diverse organic wastes (Liland et al., 2017). The black soldier fly's development is primarily a four stage cycle: egg, larvae, pupae and adult fly (Tomberlin and Sheppard, 2002; Li et al., 2011a). The egg of a black soldier fly develops to larvae, which is the 6th stage, prior to pupation and finally develops to a mature insect (Diclaro and Kaufman, 2009; Alvarez, 2012).

The BSF larvae have an innate adaptation to self-harvest because they migrate to a particular pupation zone (Sheppard et al., 1994). The adult BSF does not get attracted to human populations and environments and they do contaminate people's foods and water and therefore are not disease vectors as it does not feed and it lays its eggs near the food source (Paulk, 2006; Banks, 2014). Black soldier fly larvae have a dull whitish to brownish blackish in color and readily consume refuse and they can be harvested manually using sieves.

Figure 2.3: Adult black soldier fly

Black Solder Fly flies larvae are sometimes called loo maggots due to their association with fecal waste (Myers et al., 2008). The maggots may also be found in factory zones such as beer manufacturing plants waste pits and processing plants refuse pits such as of coffee, beans, vegetables and fish processing plant waste zones (Li et al., 2011a; Banks, 2014). The larvae can be processed as feeds for cows, swine, and various poultry species and also for aquaculture species (Newton et al., 2005a; Barroso et al., 2014; Ur Rehman et al 2017; Wang and Shelomi, 2017). Some crude fats of BSF larvae can be changed to biofuels

(Manzano-Agugliaro et al., 2012; Zheng et al., 2012; Leong et al., 2016), and one thousand larvae can produce 36g to 91g of biofuel, depending on the type of material in which they are raised (Li et al., 2011a; Li et al., 2011b). Currently black soldier fly larvae oils are been tested for use as skin care products in the multibillion beauty industry (Sangduan, 2018). According to Bava et al. (2019) as well as Chia et al. (2018) it is easy to mass produce BSF larvae for use as animal feed, thereby enhancing bioconversion as a commercial venture.

The larvae have been used to degrade the various organic wastes (Cickova et al., 2015; Gold et al., 2018; Jucker et al., 2020). In waste management while using BSF larvae, there has been shown marked difference of weight reduction of over fifty percent in weight of the fecal wastes from layer birds (Sheppard et al., 1994) and pig waste (Newton et al., 2005a; Newton et al., 2005b). Additionally, Diener et al. (2009) revealed that 66-70 % of the total weight domestic wastes were diminished by BSF larvae.

A study by Banks et al. (2014) achieved a reduction in weight of between 25-55 % of total fecal wastes when BSF larvae were used to control fresh human feces. Furthermore, maggots have been used to effectively destroy pathogenic microbes found in human or animal fecal wastes. For example, Lalander et al. (2015) concluded that *Salmonella* species in human refuse were destroyed by BSF larvae. It has also been reported that there was a significant reduction of *E. coli* bacteria 0157:H7 by BSF larvae in poultry fecal waste (Erickson et al., 2004; Liu et al., 2008).

Figure 2.4: Black soldier fly larvae

2.3 Nutritive composition of black soldier fly larvae meal

Black soldier fly larvae used as ingredients in livestock and fish diets have a good amino acid balance and high crude protein content (Table 2.1)., Spranghers et al. (2016), Tinder et al. (2017) and Jucker et al. (2020) found that BSF larvae meal protein content was high irrespective of the type of substrates on which the BSF larvae was reared. Liu et al. (2017) found that biomass quality: crude protein, crude fat and ash of the larvae varied but stabilized at mature larvae and pupae stages.

Table 2.1: The nutrition composition (% dry matter) of black soldier fly larvae meals reared on cattle and pig refuse

Analysis	BSF larvae reared on cattle refuse in percentages	BSF larvae reared on swine refuse in percentages
Crude Protein	42.1	43.6
Crude Fat	34.8	33.1
Crude fiber	7.0	Not defined
Ash	14.6	15.5

Source: Haasbroek, (2016)

There are insufficient studies on the total amino acid requirements of African catfish (*Clarias gariepinus*) and their requirements standards have been based on those of the channel catfish (*Ictalurus punctatus*) which have been studied comprehensively (Robinson *et al*. 2001; Wu et al., 2004; Robinson and Li, 2010; NRC, 2011). Table 2.2 gives the amino acid compositions of BSF larvae against the amino acid nutrient needs of the Channel catfish. However a major shortcoming of the BSF larvae meals is that it is deficient in methionine, threonine and tryptophan which are essential amino acids in the diet of the catfish (Pantazis, 2005). Nevertheless, the shortfall can be overcome by supplementation with suitable ingredients. Several studies have espoused on the high nutritive values of BSF larvae meal (Finke, 2013; Surendra et al., 2016; Barragan-Fonseca et al., 2017; Jucker et al., 2017; Nogales-Mérida et al., 2018) and as such studies have advocated for its use as an alternative feed ingredient in rearing different food animals (Marono et al., 2015; Meneguz et al., 2018). Makkar et al. (2014) found that BSF larvae meal had a favorable crude protein (CP) and crude fiber (CF) content, and as such could be utilized in place of the common protein ingredients.

Table 2.2: The relative composition (mg/g dry matter) of amino acids in black soldier fly larvae reared on various substrates against the African catfish requirements

No.	Amino Acid	BSF Larvae reared on cattle waste	BSF larvae reared on pig waste	African catfish amino acid requirements
1.	Valine	101	101	46
2.	Phenylalanine	65	67	102
3.	Tryptophan	6	27	58
4	Methionine	26	38	71
5	Threonine	16	64	45
6	Isoleucine	58	68	35
7	Leucine	104	118	108
8	Arginine	67	81	Not defined
9	Histidine	58	42	32
10	Lysine	100	100	100

Source: Haasbroek., 2016.

According to Fasakin et al. (2003) the mineral constitution of black soldier fly maggots meals depended on the processing methods and the substrates in which the maggots were reared (Newton et al., 2005a; Newton et al., 2005b). It has been reported that phosphorus content was higher in BSF larvae reared on chicken fecal waste as compared to those grown on pig fecal waste (Newton et al., 2005a) whereas calcium levels was higher in BSF larvae grown on pig fecal waste. Calcium and phosphorus levels in BSF larvae meals were adequate for the dietary needs of the African catfish.

2.4 Black soldier fly larvae and pupae as livestock feed

The characteristics of black soldier fly as a waste management tool and as a highly nutritious feed compound should be viable reasons for its adoption by farmers and institutions dealing with waste management and livestock rearing (Sheppard et al., 1994). Cured BSF larvae contain forty two percent crude proteins and thirty five percent crude fats on dry matter basis (Newton et al., 1977). Black soldier fly larvae can be easily preserved for long durations of time. Tran et al. (2015) indicated that BSF larvae can be utilized as an animal feed ingredient of most livestock species especially mono-gastric and fishes with almost all species responding positively to its inclusion in their diets.

2.4.1 Black soldier fly larvae as pig feed

Black soldier fly larvae meal diets have been shown to be viable alternatives for weaner piglets diets as they have sufficient amounts of amino acids, fatty acids and minerals such as calcium. The deficiencies of methionine, cysteine and threonine in BSFL meals can be countered by supplementing with beef offal or soya bean meals. Newton et al. (1977) reported that BSF larvae meals palatability was comparable to that of soya bean meal. Cured BSF larvae meals used to wean off piglets led to a positive outcome of over 4 % higher weight gain and over 9 % higher nutrient conversion and utilization efficiency compared to diet containing Soya Bean Meal (SBM). Nevertheless, the one hundred percent substitution with BSF did not give a favorable outcome as compared to the control where total performance reduced by close to thirteen percent.

Newton et al. (2005a) proposed further refinement of BSF larvae by removing cuticle in order to improve utilization by weaning pigs. Chia et al. (2019) reported that pigs fed BSF larvae meal compared favorably with the fishmeal fed pigs. The study also found it was economically sound to use BSF larvae meal as alternative protein ingredient in the rearing of pigs. Biasato at al. (2019) reported that piglets gained weight favorably when reared using BSF larvae meals when compared with piglets reared on the control diet (soybean meal).

2.4.2 Black soldier fly larvae in poultry diets

Black soldier fly larvae meals have been shown to enhance growth performance and hence early maturity of poultry birds especially chicken (De Marco et al., 2015; Onsongo et al., 2018). Chickens reared on feeds containing BSF larvae meal as replacement ingredient for soya bean meal (SBM) increased weight gain rates by 96% whereas the control diets having soy bean meal led to increase rate in weight gain of 93% as reported by Hale (1973) thereby showing that BSF larvae meal could be used to replace SBM in the rearing of chickens. Onsongo et al, (2018) reported that inclusion of BSF larvae meal in broiler diets enhanced feed conversion rates and nutrient utilization. Widjastuti et al, (2014) reported a significant effect on feed consumption and conversion efficiency and egg weight but there was no significant effect on egg production when fishmeal was substituted with BSF larvae in diets of quail birds (*Coturnix coturnix japonica*). When quail birds were reared with BSF larvae meal at 20 and 15% substitution rates against soybean meal diets, there was comparable growth performance and carcass characteristics as reported by Cullere et al. (2016).

In a study using broiler chicken, De Marco et al., (2015) found that BSF larvae meal was more digestible than the *Tenebrio molitor* meal. In a similar study by Al-Qazzaz et al., (2016) it was observed that egg production improved with inclusion of BSF larvae meal in the chicken diets. It was further observed that inclusion of 50 g/kg BSF larvae meal improved feed conversion efficiency (FCE), egg weight, shell thickness, shell weight, egg yolk color and fertility. The study concluded that black soldier fly can be utilized as a feed supplement for laying chicken. Maurer et al. (2015) reported that layer birds reared on BSF larvae meal performed favorably compared to the layer birds reared on soybean meal as the control.

Economically, Osongo et al. (2018) found that there was a marked increase in the Benefit Cost Ratio (BCR) by 16% and an overall increase on Return on Investment of 25% when broiler birds were fed on certain levels of *Hermetia illucens* compared to the usual diet which was 19% percent more expensive. Rearing layer birds with diets having BSF larvae meal replacing soy bean meal (SBM) led to eggs having higher yolk proportions and the yolks were deeper in color and had 11% less cholesterol compared to the eggs from chicken reared on SBM (Secci et al., 2018)

2.4.3 Black soldier fly larvae in Ruminant Diets

There is limited information on utilization of BSF larvae meal for feeding ruminants. In a laboratory study, Haasbroek (2016) observed that in-vivo and in-vitro degradability of combinations of *Hermetia illucens* and *Chrysomya chloropyga* larvae showed higher effective degradability (with low rumen un-degradable proteins) compared to full fat larvae diets of both species. It was further observed that degradability was affected by fat levels in the maggots. The study concluded that both larvae species are viable sources of proteins, polyunsaturated fats and minerals such as phosphorus and calcium that are vital for ruminant nutrition.

2.4.4 Studies on black soldier fly larvae in fish diets

Black soldier fly diets have been tested on fish species including channel catfish *(Ictalurus punctatus)*, blue St Peter's fish *(Oreochromis aureus)*, red band trout *(Oncorhynchus mykiss)*, turbot *(Psetta maxima)* and Atlantic salmon *(Salmo salar)* (Bondari and Sheppard, 1987; St-Hilaire et al., 2007a; Sealey et al., 2011; Kroeckel et al., 2012; Lock et al., 2015; Borgogno et al., 2017). These studies reported that BSF larvae meals can replace fishmeal-based diets.

Stamer et al. (2014) observed that performance of rainbow trout on BSF larvae meal was comparable to those fed on fishmeal and concluded that BSF larvae meal could be used to replace up to fifty percent fish meal in diets of the rainbow trout. In another study, Antonio, (2015) concluded that larvae meal is a viable option when rearing European Sea Bass (*Dicentrarchus labrax*) and could replace fishmeal which was more expensive and less readily available to the common farmer.

Zhou et al. (2018) found that inclusion of BSF larvae meal did not adversely affect the growth, biological and carcass quality parameters of Jian carp (*Cyprinus carpio var.* Jian). The study also found that the inclusion of BSF larvae meal diets of Jian Carp at 100% BSF larvae meal to replace fishmeal led to a decrease in n-3 highly unsaturated fatty acids in Jian carp carcasses thereby suggesting that inclusion of the larvae meal can improve on fish carcass quality.

Xiao et al. (2018) evaluated the use of BSF larvae meal in the rearing of Yellow Catfish and observed that inclusion of larvae meal (25%) increased growth performance by 29.1% (weight gain) compared to the control (with no BSFLM). Furthermore, immunity indexes improved significantly (31.9%) and all treatments did not significantly affect mortality. The study concluded that BSF larvae meal can be used to partially replace fishmeal in yellow catfish diets thereby improving on growth parameters and immuno-competence of the catfish. It is therefore reasonable to evaluate the use of BSF larvae meal in the African Cat fish. Rimoldi et al. (2019) reported that rearing rainbow trout using BSF larvae meal at different inclusion rates increased gut efficiency and as well as gut health but enabling the proliferation of beneficial microbes.

Currently there is very limited information on the use of BSF larvae meals in the rearing of the African catfish and its effects on growth performance and carcass quality parameters of the fish species. Therefore, this study aimed at addressing this gap.

2.4.5 Baker's Yeast Supplementation in Catfish Rearing.

Baker's yeast (*Saccharomyces cerevisiae)* have been investigated and found to be viable partial feed ingredient substitutes and additives especially in replacing fishmeal in fish diets. Several studies have tested the efficacy of utilizing *Saccharomyces cerevisiae* in the rearing of *Salvelinus namaycush* (Rumsey et al., 1990), *Oncorhynchus mykiss* (Rumsey et al., 1991) and in African catfish (Aderolu et al., 2011) while testing for growth performance and feed conversion efficiency. These studies found that baker's yeast could replace fishmeal by up to 50% without negating the growth performance or feed utilization of the species under study.

Other studies found that daily weight gain, feed utilization efficiency and general growth improved when Baker's yeast was fed to chicken (Angel et al., 2001; Zhang et al., 2005). *Saccharomyces cerevisiae* has also been utilized in improving feed quality characteristics such as fermentation, binding when pelleting mash meals, floatation improvement and stability of the feeds in the water especially for corn and cassava derivative feeds (Solomon et al., 2011).

Abdel-Tawwab et al. (2008) found that baker's yeast optimized growth performance, feed conversion efficiency and improved protein turn over and inclusion of 1.0 – 5.0 g yeast/kg in the diets improved the immunity of Fry Nile tilapia, *Oreochromis niloticus*. Other studies have found that use of *Saccharomyces cerevisiae* improved the growth and feed utilization efficiency as well as survivability of the African catfish (Mona et al., 2015).

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Site

The study was carried out at Kenya Marine and Fisheries Research Institute (KMFRI), Sagana Aquaculture Centre. The Centre is located about 2 km within Sagana Township in Kirinyaga County, approximately 104 Km Northeast of Nairobi City. It lies at latitudes 0019'S and 37012'E and at an altitude of 1231 meters above mean sea level. There were excellent research facilities within the station for fish research.

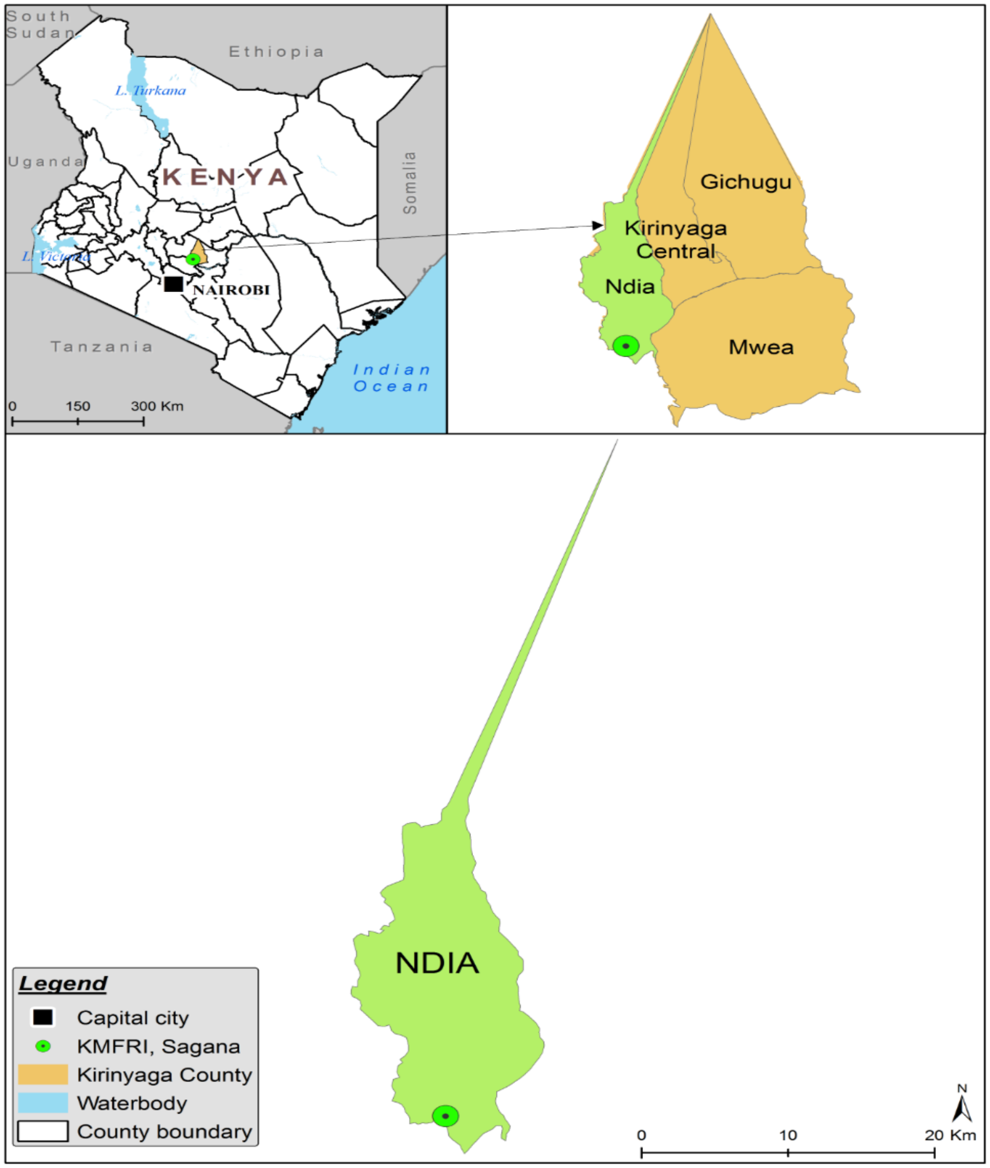

Figure 3.1: Location of Sagana Fisheries- KMFRI

3.2 Feed Ingredients

Black soldier fly larvae was sourced from International Center for Insect Physiology and Ecology (ICIPE), Nairobi, and stored in bags at room temperature until it was used in the experiment. The other feed ingredients were sourced from local suppliers, compounded, mixed and formulated to make a mash as complete fish diets. The diets were formulated to meet optimum feeding standards for Catfish as shown in Table 3.1 (NRC. 2011; Munguti et al., 2014)

Table 3.1: Dietary composition of catfish feeds and feeding rate used in the study during the six month study period

Parameter	**Fingerlings**
Feeding rate	6 – 8 %
Crude Protein	35 – 40 %
Energy MJ/Kg	10.5 – 11.0
Crude fiber	≥ 4%
Lipids	≥ 12%
Premix	200g/20kg

The diets were formulated to partially or wholly replace fishmeal with BSF larvae meal. The control diet (C) contained fishmeal as the protein source and with no BSF larvae meal. For diets D1, D2, D3 and D4 BSF larvae meal was included to replace fishmeal at inclusion rates of 25%, 50%, 75% and 100%. Diet D5 contained both fishmeal and BSF larvae meal at 49 % each but also included baker's yeast at 2%.

Table 3.2: Formulated treatment diet (kg) compositions used in the study.

Ingredients	**C**	**D1**	**D2**	**D3**	**D4**	**D5**
Pollard	38.90	32.10	25.30	18.50	7.50	25.10
Fishmeal	60.90	47.70	34.60	21.40	0.00	34.80
BSFL	0.00	20.00	39.90	59.90	92.30	39.70
Premix	0.20	0.20	0.20	0.20	0.20	0.20
Baker's Yeast	0.00	0.00	0.00	0.00	0.00	0.20
Total	100.00	100.00	100.00	100.00	100.00	100.00
CP (%)	40.03	40.03	40.03	40.04	40.03	40.03
Me (Kcal/Kg)	2779.90	2804.50	2828.90	2853.60	2893.30	2822.80
Crude Fat (%)	10.77	15.50	20.21	24.90	32.60	20.17

C, Control diet (0% BSF larvae meal and 100% fishmeal); D1, Diet 1 (25% BSF larvae meal and 75% fishmeal); D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal); D5, diet 5 (49 % BSF larvae meal, 49% fishmeal and baker's yeast at 2%)

3.3 Experimental fish

Five hundred two-month old male African cat fish of uniform sizes were sourced from KMFRI Sagana center. Three hundred and sixty pieces were used in the experiment in eighteen harper nets. The rest were stored and used for replacement when mortality occurred. The sample catfish fingerlings were acclimatized in the study pond for one week prior to the start of the feeding study to minimize mortality in the course of the study. The catfish were fed twice a day at 8:00 am and at 3:00 pm. Feed intake was 8% of the total body weight.

3.4 Experimental Design and Procedures

The study design was a completely randomized design (CRD) with a total of eighteen (18) harper nets with each harper net holding twenty (20) catfish. Each treatment was replicated three (3) times. The harper nets were made of net made into 2 by 2 by 2 m cuboid. The harper nets were then installed in one large earthen fish pond prior to the start of the experiment. The data collection was carried out for 6 months.

3.4.1 Data collection

During data collection, the sample catfish were removed from the net cages and transported in a bucket filled with some water so as to minimize stress and possible deaths. Each of the 20 catfish from each cage as per the treatment diet were weighed and their lengths taken. All measurements on body weight, feed intake, and carcass weight were carried using a digital weighing balance (KERN

EWISOO- 2M). Lengths of the experimental catfish were measured with a board trough standardized meter ruler as shown in figure 3.2.

Figure 3.2: Ruler board used to measure the lengths of the sampled catfish

3.4.2 Feed and carcass sample analysis

All treatment diets, diet ingredients as well as the African catfish carcasses were analyzed using the Association of Analytical Chemists (AOAC, 1995) guidelines.

The ash amounts were realized through heating at 550°C for 12 hours. Ether extracts were extracted with Velp solvent extractor (SER 148/6) and ethyl ether was used as the extracting solvent. Kjeldahl method was used to determine the crude protein levels by multiplying N (%) derived from each sample with the 6.25 factor (Mariotti et al., 2008).

3.4.3 Calculations on parameters measured

i. Growth parameters; length (cm), weight (g), daily weight gain (DWG, g day-1), weight gain (%), SGR% and FCR were calculated as follows:

   a) WG (weight gain) = final weight of fish – initial weight of fish
   b) ADGW (weight gain) = {final weight of fish – initial weight of fish} ÷ total experimental days
   c) Specific growth rate (SGR % per day) = {(final body weight – initial body weight) ÷ days} × 100
   d) FCR = Feed given ÷ animal weight gain

ii. Survival (%)

   SR (survival rate %) = (number of initial fish ÷ number of final fish) ×100

iii. Carcass quality parameters; proximate composition including crude protein (CP), crude fiber (CF), ether extract (EE), ash and amino acids composition (Methionine; Lysine; Leucine; Isoleucine; Valine; Phenylalanine, tyrosine; Arginine).

iv. Water quality test including pH, salinity, dissolved oxygen.

3.4.4 Amino acids derivatization

The methods of crude protein extraction were adopted from Hamilton et al., (2012) and detailed in Musundire et al., (2016). Briefly, approximately 25mg of defatted African catfish finely ground sample was weighed into Pyrex tubes. Five ml 6 N hydrochloric acid (HCl) was added and mixed carefully and purged with nitrogen for 30 seconds. The Pyrex tubes were caped immediately and soaked in boiling water for 10 minutes. The Pyrex tubes were placed in 110^{o}C oven for 24 hours to dry. The samples removed from oven and allow to cool and vortexed for 10 seconds. The hydrolysates were quantitatively transferred through Whatmann N^{o} 1 filter paper into 10 ml falcon tube. The Pyrex tubes were rinsed with distilled water and each of the washings from each Pyrex tube was used to fill to mark.

A volume of 0.3µL of the filtrate was injected into a Liquid chromatography–mass spectrometry (LC-MS) for chromatographic separation, identification and quantification of amino acids. The results were analyzed using Enhanced ChemStation (MSD ChemStation F.01.00.1903) to realize to concentrations of the essential amino acids and further analyzed for statistical significance.

3.5 Statistical Analysis

Collected weights and lengths were recorded in workbooks and the raw data was transferred into excel spreadsheets for organization and cleaning. Analysis of variance was performed using Statistical Analyses Software (GenStat 15th Ed.

Version 15.1.0.8035) and significantly different means were separated by using Tukey's Test at $P < 0.05$ (Tukey, 1991).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Chemical Composition of Diets and Ingredients

Results of proximate analysis of BSF larvae meal and all the feed ingredients used during the study are shown in Table 4.1 below. The crude protein of fishmeal was 72.4% DM while that of BSF larvae meal was 47.4% DM. The ether extracts was 41.5% DM and 15.59% DM for BSF larvae meal and fishmeal respectively.

Table 4.1: Mean (±SE) Chemical composition (% dry matter) of oven dried black soldier fly larvae meal, fishmeal, pollard and baker's yeast

Parameter	BSFL Meal	Fishmeal	Pollard	Baker's Yeast
Dry Matter	85.17±0.167	88.33±0.441	89.83±0.441	91.85±0.153
Crude Protein	47.40±0.516	72.40±0.187	12.90±0.122	40.81±1.189
Ether Extracts	41.53±3.341	15.59±0.273	10.92±0.286	0.47±0.003
Ash	9.98±0.340	14.50±0.370	10.80±0.323	5.40±0.322

The CP levels of the formulated fingerling diets attained the minimum nutritional requirements of 35-40% of catfish (Adebayo and Alasoadura, 2001; Ali, 2001; Adewolu and Aro, 2009). The diets in all the treatments had a crude protein of between 41.1% and 48.2% as shown in table 4.2. The results of proximate and chemical analysis showed that the six treatment diets were similar in nutrient composition although they had slight non-significant variations.

Table 4.2: Mean (± SE) chemical compositions (% dry matter) of treatment diets used in the study

Diets	DM (%)	CP	Ash	EE
C	87.19±0.426	41.12±0.599	16.05±0.440	21.95±0.305
D1	88.33±0.441	41.44±1.524	14.53±0.370	20.50±0.567
D2	85.17±0.167	48.19±0.295	14.81±0.681	21.19±0.526
D3	85.67±0.333	46.88±1.059	16.73±0.367	22.64±0.779
D4	86.00±0.577	45.82±0.657	18.31±0.203	21.59±0.581
D5	86.67±0.667	45.22±0.358	17.94±0.534	21.37±0.617

DM, Dry matter; CP, crude protein; EE, Ether extract; C, Control diet (0% BSF larvae meal and 100% fishmeal); D1, Diet 1 (25% BSF larvae meal and 75% fishmeal); D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal); D5, diet 5 (49 % BSF larvae meal, 49% fishmeal and baker's yeast at 2%)

4.2 Water Quality Analysis

The water essential parameters: temperature and dissolved oxygen varied throughout the study period, with daytime temperature and dissolved oxygen ranging from 24.5 to 31.5°C and 6.2 to 12.1 g/L respectively as shown in Table 4.3. The temperature and dissolved oxygen levels were within the acceptable limits for rearing African catfish (Ogunji and Awoke, 2017).

The pond water characteristics assessed in this experiment were similar in all the treatments as the catfish were reared in one pond that had an inlet supply from one of the tributaries of Sagana River and an outlet that emptied into a canal emptying into other ponds. In general low levels of dissolved oxygen, temperature and water pH tend to retrogressively affect the growth performances of fish (Summerfelt, 2000). In this study the mean water characteristics values of dissolved oxygen, temperature and pH were within the recommended levels as shown in Table 4.3 for rearing the African catfish.

Table 4.3: The water quality parameters taken in the course of the study

Parameter	Mean	Min	Max	Optimum range
pH	8.45	8.10	9.18	6.50 – 10.501
Conductivity	107.12	80.00	124.00	65.00- 130.00
Temperature (°C)	27.02	24.08	30.43	23.00 – 35.00
Total Dissolved Solids (mg/l)	53.34	41.00	62.00	35.00 – 174.70
Dissolved oxygen (mg/l)	9.75	7.50	13.57	3.00 – 14.00
Salinity g/l	0.05	0.04	0.06	<2.50

4.3 Survival and Mortality

The survival rates at the end of six month study period were 98.90% in all the treatment groups**.** Survival was constant throughout the course of the study other than three catfish fingerlings that were unaccounted for from cages for treatment diets C and D1 as shown in Table 4.4. The fingerlings were thought to have escaped into the larger fish pond or died.

Table 4.4: The survival and mortality (averages) of the African catfish during the six month study period as per treatment diet.

Treatment diet	**Initial stocking**	**Final stock**	**Mortality**
C	20	19	1
D1	20	19	1
D2	20	20	0
D3	20	20	0
D4	20	20	0
D5	20	20	0

C, Control diet (0% BSF larvae meal and 100% fishmeal); D1, Diet 1 (25% BSF larvae meal and 75% fishmeal); D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal); D5, diet 5 (49 % BSF larvae meal, 49% fishmeal and baker's yeast at 2%)

This findings on mortality tally with previous experiments using BSF larvae meal either as partial or full replacement diets in place of fishmeal in the diets of white shrimps (Cummins et al., 2017) and in poultry broiler feeds (De Marco, et al, 2015; Schiavone et al., 2017; Onsongo et al., 2018), Nile tilapia (Devic et al., 2018), Jian carp (Zhou et al., 2018), rainbow trout (Cardinaletti et al., 2019), zebrafish (Vargas et al., 2018) and the clownfish (Vargas et al., 2019). Moreover the utilization of house fly maggot meal at different inclusion levels in the rearing of yellow catfish showed that its utilization had no significance on survivability but group replacement survival rates were lower (98.8% - 99.4%) than for the diets treatments without maggot meal (Wen et al., 2013). Devic et al. (2018) reported higher concentration of BSF larvae meal (80%) resulted to increased mortality of up to 10% in the rearing of the Nile tilapia. The current study also realized better survival rates than those reported by Fasakin et al. (2003) which had 70% to 72.5% when African catfish fingerlings were fed diets containing house fly maggots.

Renna et al. (2017) reported that the survival rates of rainbow trout reared on BSF larvae meals at inclusion rates of 25% and 50% were not negatively affected as compared to the treatment diets without BSF larvae meal. These findings correspond with the current study with the same inclusion rates. Further study by Józefiak et al. (2019) while utilizing BSF larvae meal in the rearing of the Siberian sturgeon reported that survival rates of the test fish were not negatively affected thus giving credence to the current study.

4.4 Growth Performance

The changes in weight are shown in Table 4.5. Length gain is shown in Table 4.6 and the specific growth rate and feed conversion ratio are shown in Table 4.7. The graph (Figure 4.2) is showing length gain over the study period. Treatment diet D2 was the best performing in terms of length gain followed by D3. The least performing diet in terms of length gain was diet D4.

Table 4.5: Mean (± SE) weights gain in grams of catfish fed on various BSF larvae meal and fishmeal diets over the six month study period

DIET	Initial weight	Final weight	Weight gain	ADGW
C	3.44±0.322	84.79±2.595b	81.35±2.352b	0.55±0.016b
D1	3.58±0.121	90.87±2.511b	87.29±2.612b	0.59±0.018b
D2	4.18±0.083	154.60±4.175a	150.40±4.218a	1.01±0.028a
D3	4.01±0.194	149.39±2.170a	145.39±2.243a	0.98±0.015a
D4	3.50±0.202	92.02±1.947b	88.52±1.839b	0.59±0.012b
D5	3.62±0.227	72.98±14.32b	69.36±14.100b	0.47±0.095b
P value	0.131	< 0.001	< 0.001	< 0.001

Within columns, means followed by same lowercase letters are not significantly different at P < 0.05; ADGW, Average daily gain in weight; C, Control diet (0% BSF larvae meal and 100% fishmeal); D1, Diet 1 (25% BSF larvae meal and 75% fishmeal); D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal); D5, diet 5 (49 % BSF larvae meal, 49% fishmeal and baker's yeast at 2%)

Initial weights of the catfish fingerling were not significant (P<0.05) whereas final weights were significantly higher (P<0.05) for treatment diets D2 and D3 as shown in Table 4.5. Average daily gains in weight for treatment diets C and D5 were lower as compared to treatment diets D2 and D3. Treatment diets D1 and D4 had similar average daily gains in weight.

Table 4.6: Mean (±SE) length gain in centimeters of catfish fed on various BSF larvae meal and fishmeal diets over the study period of six months

Diet	initial length	final length	length gain	ADGL
C	8.36±0.241	24.42±1.661ab	16.06±1.645ab	0.11±0.011ab
D1	8.35±0.143	25.08±0.689ab	16.73±0.821ab	0.11±0.006ab
D2	8.75±0.022	29.10±0.577a	20.38±0.598a	0.14±0.004a
D3	8.62±0.167	27.57±0.530ab	18.95±0.614ab	0.13±0.004ab
D4	8.25±0.026	22.76±0.676b	14.51±0.685b	0.10±0.005b
D5	8.36±0.151	23.11±1.697b	14.75±1.582b	0.10±0.011b
P value	0.201	0.008	0.014	0.014

Within columns, means followed by different lowercase letters are significantly different at P < 0.05; ADGL, Average daily gain in length; C, Control diet (0% BSF larvae meal and 100% fishmeal); D1, Diet 1 (25% BSF larvae meal and 75% fishmeal); D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal); D5, diet 5 (49 % BSF larvae meal, 49% fishmeal and baker's yeast at 2%).

The lengths of the catfish fingerlings were uniform during the stocking stages for all treatment diets as shown in Table 4.6 whereas the final lengths during the termination of the study were varied with the longest lengths recorded for treatment diets D2 and D3. The daily gains of length for the catfishes were also very varied though there was significance for treatment diets D2 and D3.

Table 4.7: Mean (±SE) feed conversion ratio and specific growth rate of catfish fed on various BSF larvae meal and fishmeal diets over the six month study period

Diet	SGR % per day	FCR
C	48.42±1.400b	4.74±0.138ab
D1	51.96±1.555b	4.42±0.132ab
D2	89.53±2.511a	2.56±0.070b
D3	86.54±1.335a	2.65±0.041b
D4	52.69±1.095b	4.35±0.091ab
D5	41.29±8.393b	6.19±1.577a
P value	< 0.001	0.016

Within columns, means followed by same lowercase letters are significantly different at P < 0.05; SGR, Specific growth rate; FCR, feed conversion ratio; C, Control diet (0% BSF larvae meal and 100% fishmeal); D1, Diet 1 (25% BSF larvae meal and 75% fishmeal); D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal); D5, diet 5 (49 % BSF larvae meal, 49% fishmeal and baker's yeast at 2%)

Feed conversion was significantly higher in treatment diets D2 and D3 and lowest in treatment diet D5 as shown in table 4.7. Specific growth rate was significantly higher in treatment diets D2 and D3 and significantly lower in all the other treatment diets. Growth responses observed from the experiment were significantly influenced by the content of black soldier fly meal in the diet. Across all feeding regimes, weight gain and length gain increased gradually from the start of the study as shown in Figure 4.1. Weight gain gradually increased for all treatment diets and the increase was more noticeable after week 10 for D2 and D3 each having 50% and 75 % BSF larvae meal respectively. This was followed by the fish consuming D1 and D4 while the control diet (C) was the third in terms of performance. The least performing treatment diet was D5 which had 2% Baker's yeast as an additive. Weight gain was significant ($P < 0.05$) at BSF larvae meal inclusion level of 50% and 75%.

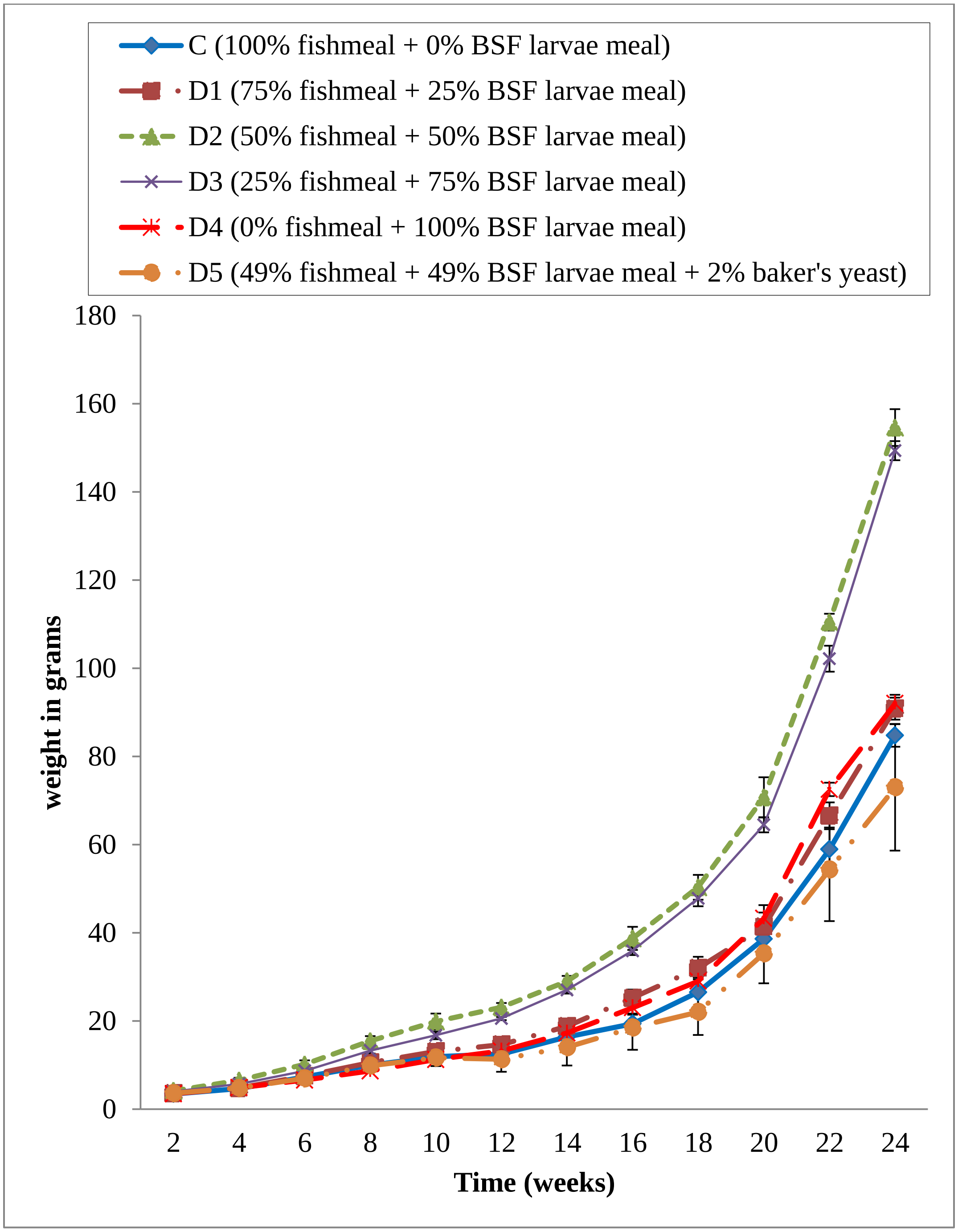

Figure 4.1: Weight gain of the catfish fed different rations of black soldier fly larvae meals during the study period

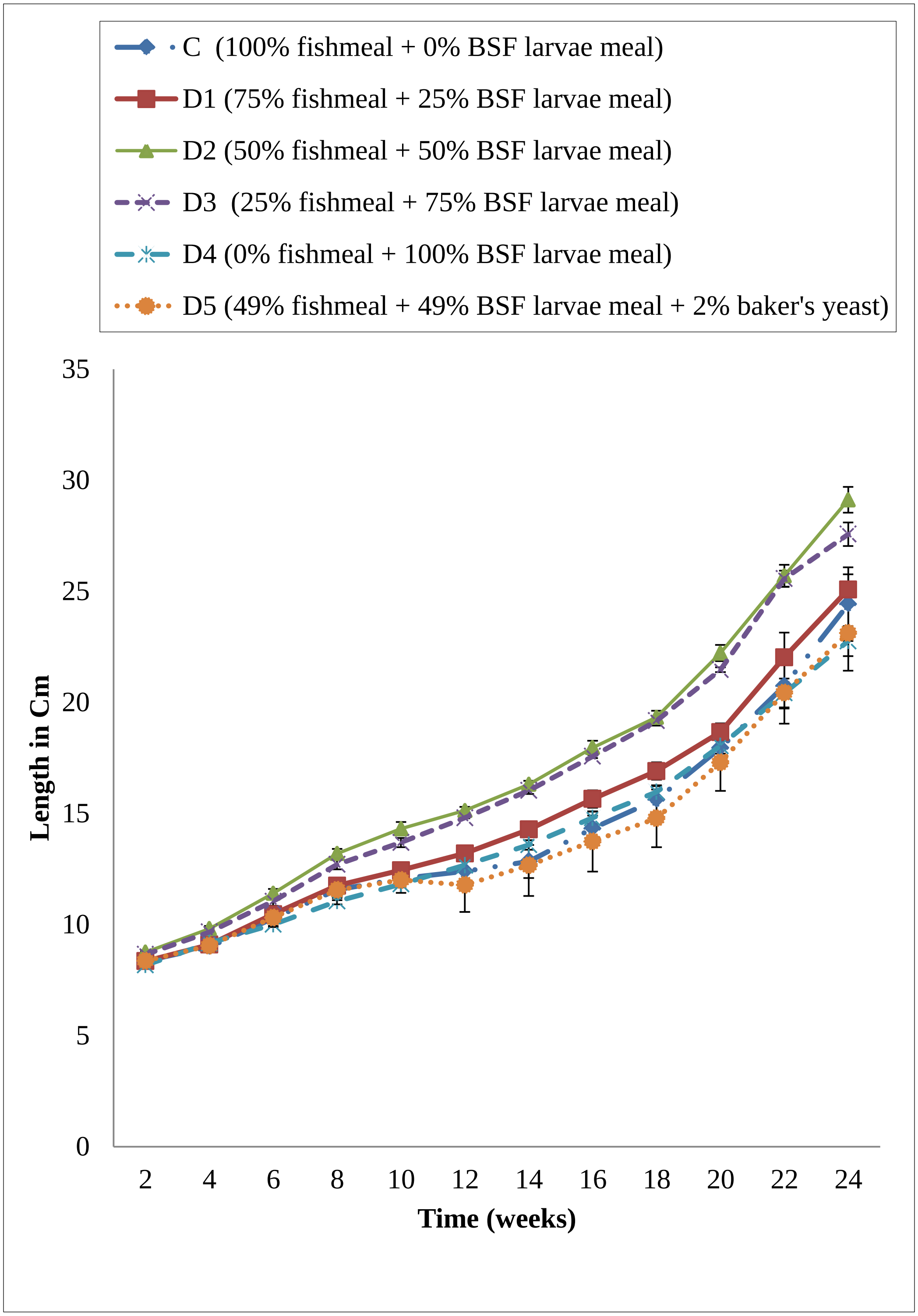

Figure 4.2: Changes in the length over time of catfish in the six diet groups.

Growth performance from the present study was comparable to those from other previous experiments (Wen et al., 2013; Cummins et al., 2017; Zarantoniello et al., 2018) with very little differences. The differences were attributed to the fact that ages of fish and species used in the studies were different. Differences in composition and formulation of treatment diets and rearing conditions of the fish may also have contributed to the varied results (Wen et al., 2013; Yu et al., 2013). In the current experiment, treatment D2 (50% BSF larvae meal) and D3 (75% BSF larvae meal) performed the best and 100% replacement fishmeal with BSF larvae meal which performed poorly just like the control having 100% fishmeal.

The results are in agreement with those reported by Bondari and Sheppard (1987) who found that 100% replacement of fishmeal with BSF larvae meal in the diets of channel catfish or blue tilapia greatly suppressed the growth rates. Partial replacement of fishmeal with the use of BSF larvae meal as in this study showed that there was a better performance up to 75% BSF larvae meal inclusion and this was contrary to other studies (St-Hilaire et al., 2007a; Sealey et al., 2011).

Weight gain rates in this study of the African catfish fed on fishmeal was similar to Lock et al. (2015). High levels of BSF larvae meal (120- 300 g/kg) negatively affected growth rates and feed conversion rates of *Psetta maxima* and in *Oncorhynchus mykiss* (St-Hilaire., 2007a; Kroeckel et al., 2012; Borgogno et al., 2017) whereas above 330 g/kg rates of inclusion suppressed palatability of the treatment diet, intake of feeds, and growth rates of *Psetta maxima* (Kroeckel et al., 2012). Higher levels of inclusion of BSF larvae meal has been thought to suppress digestibility of feeds and growth rates of fish reared. Karapanagiotidis et al. (2014) reported that the gilthead seabream reared on BSF larvae meal at 30% in replacement of fishmeal increased the growth rate and this correlates with the current study where treatments D1, D2 and D3 had noticeable growth rate changes. Weight gain in the rearing of the rainbow trout while using BSF larvae meal at inclusion rates of 25% and 50% did not significantly differ ($P<0.05$) from the control diet unlike in current study which found that inclusion rates 50% led to improved weight gain of the African catfish. The weights of the larval zebrafish wasn't negatively affected by the inclusion of BSF larvae meal (Zarantoniello et al., 2019) contrary to the current study which found that total substitution of fishmeal with BSF larvae meal was significantly ($P<0.05$) lower.

At 50% and 75% BSF larvae meal inclusion rates, weight gain was similar to that observed in previous studies. Belghit et al., 2018 and Belghit et al., 2019 reported that the Atlantic salmon had improved growth when it was reared using BSF larvae meal at inclusion rates of 50 – 60% and that the growth was threefold 49g to 137g in 56 days. Magalhães et al. (2017) reported that inclusion rates of BSF larvae meal at 50% improved growth rates of the European seabass thereby giving credence to the current study where 50% BSF larvae meal inclusion resulted to higher growth performance. The juvenile Barramundi, *Lates calcarifer* gained weight significantly ($P<0.05$) and performed better when fed diets containing BSF larvae meal thereby demonstrating that it can be utilized as a partial replacement to fishmeal without negatively affecting the growth performance of the fish (Katya et al., 2017). The study also found that with fishmeal substitution, weight gain and specific growth rate decreased though not significantly when compared to the fish fed fishmeal or those fed BSF larvae meal as the sole protein source. Dumas et al, (2018) reported that use of BSF larvae meal in the rearing of the rainbow trout enhanced growth as the thermal growth coefficient increased with each increase in unit of BSF larvae meal (above 26.4%) and this correlates with the current study where more than 25% inclusion rates of BSF larvae meal improve the growth rates of the African catfish when compared to the control diet fishmeal.

Vargas et al. (2019) reported that clownfish fed BSF larvae meals did not perform any different from the control treatment diet without BSF larvae meal contrary to the current study which found that inclusion of BSF larvae meal at 50% and 75% rates improved growth performance. The growth rates rainbow trout reared on BSF larvae meal at inclusion rates of 50% were not affected negatively as reported by Renna et al. (2017) and this corresponds with the current study where D2 (50% BSF larvae meal) had significantly higher ($P<0.05$) weights as compared the control diet C (0% BSF larvae meal). While using BSF larvae meal as a test ingredient at 15% inclusion rates in the rearing of the Siberian sturgeon, Józefiak et al. (2019) reported that growth rates were not negatively affected thereby supporting the results of the current study where inclusion of the test ingredient did not affect negatively the growth in treatment diets D2 and D3.

Previous studies have shown that different protein source combinations improved growth performances of the fishes than when one source of protein was utilized.

This observation was attributed to the synergisms from the different protein sources (Sogbesan and Ugwumba 2008; Alegbeleye et al., 2012; Collins et al., 2013; Djissou et al., 2016). The control diet had only one protein source as compared to all the other treatment diets and hence the growth performance was better in all the treatments other than the control diet. When BSF larvae meal was used to rear *O. aureus* (Bondari and Sheppard, 1981) either when used as the sole feed or on combinations with other feed ingredients, growth performance in terms of weight gain and lengths were similar to the control diets unlike in this study where body weights (BW) and body length (BL) were different. In another study by Bondari and Sheppard (1987) growth performance of the blue tilapia fed on BSFL as the sole feed ingredient had lower weight gain just like in the current study though in the previous study the BSF larvae meal utilized had lower amounts of crude protein as compared to the larvae used in this study.

The results of this study agreed with those of previous studies which suggested that addition of insect in fish feeds increased growth or performed equally to the diets containing fishmeal especially at 50% insect meal inclusion rates (Wing-Keong et al., 2001; Alegbeleye et al., 2002; St-Hilaire et al., 2007b; Cummins et al., 2017) in diverse rearing systems and fish species. Like in the present study, higher amounts (above 75% inclusion rate) of insect meals negatively affected the growth rates of different fish species and this can be attributed to the high levels of chitin (Sanchez-Muros et al., 2014; Sanchez-Muros et al., 2015) and the limited amounts of essential amino acids (Cummins et al., 2017). While using BSF larvae meals (Stadtlander et al., 2017) in the rearing of the rainbow trout in an on farm experiment, it was found that growth indexes such as weight gain and body length were significantly ($P<0.05$) higher, which agree with the results of the current study.

The feed conversion ratios (FCR) in the current study were lower compared to other studies and this may be attributed to the high amount of chitin in the BSF larvae meal. The exoskeletons of insects contain chitin and being an unbranched polymer of N-acetylglucosamine, chitin is not easily digestible by most species of fish (Smith et al., 1989; Esteban et al., 2001; Kroeckel et al., 2012; Henry et al., 2015; Magalhaes et al., 2017; Renna et al., 2017) due to the lack of enzyme chitinase (Rust, 2002; Cummins et al., 2017) and appropriate gastro-intestinal tract microbiota especially bacteria. Other studies have shown that 10 g/kg of chitin did not negatively affect the growth rate of common carp (Gopalakannan and Arul, 2006). It has been found that the proximate chitin levels of most insect meals ranges between 11.6 to 137.2 mg/kg in DM (Finke, 2007) and therefore treatment D3 containing high levels of BSF larvae meal may negatively affect the growth rates of the African catfish although Jian carp performed better under the same feeding regimes (Zhou et al., 2018). The study by Ng et al. (2001) found that use of Mealworm larvae (*Tenebrio molitor)* as an alternative to fishmeal in the rearing of the African catfish resulted in better growth and enhanced feed conversion efficiency as well as improved total carcass nutritive characteristics and this results of the previous study agree with the current study with the African catfish.

Some fish species such as the red tilapia (*O. niloticus X O. hornorum*) and the Nile tilapia utilized significantly high amounts of shrimp meals which have high levels of chitin without negatively affecting the growth performance of the fish (El-Sayed, 1998). In other studies, rearing of *O. niloticus x O. aureus*, chitin in the feeds negatively affected the performance of the fish (Shiau and Yu, 1999). The observations from this study suggest that the African catfish (*Clarius gariepinus)* may have little or no efficiency in utilizing chitin which is high in BSF larvae meals.

There was a notable slower growth rate for treatment D5 as compared to the treatment D2 and this can be attributed to the fact that herbivorous fishes tend to be better in utilization of Baker's yeast compared to omnivorous and carnivorous fishes. These findings are contrary to Aderolu et al. (2011) and Manoppo and Magdalena, (2016) who found that Baker's yeast enhanced growth and feed conversion efficiency while rearing the African catfish and common carp (*Cyprinus carpio)* respectively. Angel et al. (2001) and Zhang et al. (2005) found that use of Baker's yeast enhanced growth, feed conversion efficiency and daily weight gain in the rearing of chickens. The findings of the above studies do not tarry with the present study in that in the current study growth and feed conversion efficiency were lowest in treatment D5 that had Baker's Yeast.

Mona et al. (2015) found that use of baker's yeast (BY) as an additive in catfish feeds at a rate of 2% improved growth performance and enhanced feed conversion rates unlike in this study that shows otherwise. Other studies found that use baker's yeast (BY) as a feed additive at a low inclusion rate enhanced growth and carcass quality parameters (Kobeiusy and Hussein, 1995; Abdel-Tawwab et al., 2008) and though in this study growth performance was negatively affected, carcass characteristics were not significantly (P<0.05) different from all the other treatment carcasses.

However, the results for Treatment D5 that had baker's yeast (BY) conformed with those of other studies such as Salnur et al. (2009) and Solomon et al. (2017) who found that the different fish species did not achieve enhanced growth performance and in fact the use of baker's yeast (BY) negatively affected growth rates and feed conversion rates. Rumsey et al. (1991) found that the rainbow trout did not tolerate high amounts of baker's yeast (BY) and in fact any increase in concentration of baker's yeast (BY) in the feeds significantly (P< 0.05) reduced growth and feed conversion rates.

4.5 Carcass Characteristics

The proximate analysis on carcasses indicate that fish fed on D2 (BSFL meal was 50%) had the highest crude protein at 75.0% while D4 had the lowest at 65.2%. Treatment diets D2 and D4 had significantly (P<0.05) higher crude protein levels whereas diet D4 had significantly lower levels of crude protein as shown in Table 4.8. Ether extracts were significantly lower (P< 0.05) in carcasses harvested from control diet C. There was a numerical increase in the amounts of ether extracts of the diet carcasses harvested from treatment diets D1 to D4 though the increases were not significantly different at P<0.05.

Table 4.8: Means (±SE) of proximate composition (% dry matter) of the analyzed carcasses harvested at the termination of the study

Diet	Dry matter	Ash	Crude protein	Ether extracts
C	90.35±0.348	16.42±0.304a	67.28±0.566bc	15.62±0.071b
D1	90.20±0.425	16.45±0.258a	67.32±0.689bc	22.44±0.143a
D2	92.50±0.500	13.70±0.970a	75.04±0.830a	25.04±2.365a
D3	92.36±1.334	13.73±0.551a	72.21±1.389ab	26.57±0.728a
D4	91.33±0.601	15.51±0.399a	65.21±0.915c	28.85±2.330a
D5	90.70±0.174	15.07±0.689a	68.61±2.915abc	23.06±0.318a
P value	0.121	0.016	0.004	< 0.001

Within columns, means followed by same lowercase letters are not significantly different at $P \geq 0.05$; C, Control diet (0% BSF larvae meal and 100% fishmeal); D1, Diet 1 (25% BSF larvae meal and 75% fishmeal); D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal); D5, diet 5 (49 % BSF larvae meal, 49% fishmeal and baker's yeast at 2%)

Results from the proximate chemical analysis of the carcasses of the six treatment diets showed that the treatment diets did not influence significantly ($P<0.05$) the chemical composition of the African catfish except for the CP levels that varied significantly ($P<0.05$) for treatment diets D2 (50% BSF larvae meal) and D3 (75%

BSF larvae meal). The crude protein of the carcasses fed on the two diets were above 70% thereby showing that medium inclusion rates of BSF larvae meal in catfish diets led to increased carcass protein levels. A 100% inclusion rate of BSF larvae meal in catfish diets led to an increased level of carcass fat percentage (28.85%) and such high body fat levels render the catfish to be of poor quality and spoils faster (Hasan et al., 2016). In addition, excessively fatty catfish is undesirable because it is not easy to fillet.

The current study also found that whole-carcass chemical analysis of the catfish was not significantly affected by the inclusion of BSF larvae meal in the different experiment diets. The percent CP of the carcasses was significantly higher ($P< 0.05$) in treatment diets D2 and D3 compared to all the other treatment diet carcasses. Previous studies such as Katya et al. (2017) found that carcass compositions were not affected by the inclusion of BSFL in the rearing of juvenile Barramundi, *Lates calcarifer*. Others studies have also shown that there were no significant differences in whole carcass chemical composition especially with regard to percentage CP of trout fed different amounts of BSF larvae meal (St-Hilaire et al., 2007a; Zarantoniello et al., 2018). Cummins et al. (2017) found that the nutrient proximate composition of shrimp carcasses wasn’t significantly influenced with the different feeding levels with dietary BSF larvae whereas Zarantoniello et al. (2019) reported that rearing of the zebrafish using BSF larvae meal did not negatively affect the proximate composition of the harvested carcasses just like in the current study.

Whole carcass lipid amounts increased with increasing amounts of BSF larvae meal in the treatments and similar observations have been made elsewhere (Lim et al., 2000; Ng et al., 2001; Nyina-wamwiza et al., 2007). In a study in an on farm experiment Stadtlander et al. (2017) found that the end product quality of feeding rainbow trout was not negatively affected by increasing BSF larvae meal in the feed.

Treatment diet D5 had comparable carcass proximate characteristics with the other treatment diets in this study and this findings correlate with other studies (Kobeiusy and Hussein, 1995; Abdel-Tawwab et al., 2008; Solomon et al., 2017), that found that use of baker's yeast as an additive resulted in improved carcass merits of different fishes. In other studies (Murthy and Gatlin, 2006; Zehra and Khan, 2016), it was found that there was no effect on the carcass characteristics when baker's yeast (BY) was used as a feed additive. It is worth noting that Lunger et al. (2006) and Oz´orio et al. (2012) found that the body proximate composition was affected by use of baker's yeast (BY) while feeding the Nile tilapia and the African catfish in that total protein reduced as baker's yeast concentration increased. At an inclusion rate of 4% BY as in Aderolu et al. (2011), African catfish responded well in terms of growth performance and total protein was higher whereas in the same study, 2% baker's yeast inclusion rate did not improve carcass merit just like in the current study.

The results of the current study show that use of BSF larvae meal in the rearing of the African catfish does not affect the carcass proximate and quality characteristics and this is in line with other studies (Zarantoniello et al., 2018; Cardinaletti et al., 2019; Józefiak et al., 2019; Zarantoniello et al., 2019).

4.5.1 Amino acid profile

The carcasses from all the six treatment diets were analyzed for the essential amino acids including arginine, methionine, lysine and histidine, lysine. All the essential amino acids analyzed in this study were found to be higher in catfish fed BSF larvae meal up to 100% inclusion rates compared to African catfish reared on fishmeal which was the control diet. Statistical differences were noted among the different treatment diet carcasses as shown in Table 4.9.

Treatment diet D3 (75% BSFLM) and D4 (100% BSFLM) had almost similar amounts of essential amino acids whereas treatment diets D2 (50% BSFLM) and D5 (49% BSFLM, 49% FM and 2% BY) had almost similar amounts of essential amino acids. Arginine was highest in treatment diet D5, methionine was highest in treatment diet D4 (33.03 mg/g CP) and there was no significance ($P<0.05$) for phenylalanine in diet carcasses from D1 and D2.

There is very scarce information concerning studies involving insect diets and their effect on the amino acid content in fishes. Amino acids especially essential ones are always higher in amounts in whole carcasses of fish fed non fishmeal diets (Katya et al., 2017). In this study, overall analysis on carcasses of African catfish fed BSF larvae meal showed variability on the amino acid content within treatments. Carcasses from treatment D5 had comparable essential amino acids

(EAA) with all the other treatment diets meaning that inclusion of baker's yeast in BSF larvae meal diets did not compromise on the quality of amino acid in the end product. Indeed all the treatment diets resulted in favorable essential amino acids.

Table 4.9: Means (±SE) of essential amino acid profiles of the African catfish carcasses in mg/g CP DM

Amino acid	C	D1	D2	D3	D4	D5	P value
Arginine	10.07±0.260d	20.03±1.281c	26.48±0.953b	34.07±0.146a	35.08±0.366a	33.96±0.463a	<0.001
Histidine	9.67±0.196c	19.75±1.248b	22.93±1.490b	31.92±0.203a	32.34±0.245a	20.84±0.214b	<0.001
Isoleucine	6.79±0.123d	14.72±0.197c	15.84±0.144b	18.76±0.185a	19.54±0.342a	16.78±0.314b	<0.001
Leucine	11.74±0.157c	17.34±1.119b	18.09±0.252b	21.45±0.095a	22.74±0.237a	18.49±0.731b	<0.001
Lysine	14.21±0.179d	24.24±1.291c	25.33±0.603bc	28.86±0.850ab	29.92±0.917a	25.83±0.192bc	<0.001
Methionine	4.80±0.239c	17.98±1.575b	30.95±0.812a	31.11±0.424a	33.03±0.459a	29.75±0.331a	<0.001
Threonine	6.07±0.121c	12.07±1.042c	18.99±0.233b	25.34±0.737a	26.29±0.303a	19.46±0.222b	<0.001
Phenylalanine	6.32±0.296c	20.38±0.698b	20.81±0.763b	28.09±0.264a	28.63±0.210a	21.42±0.286b	<0.001
Valine	9.91±0.184e	14.22±0.580d	16.13±0.328c	18.87±0.192ab	19.64±0.063a	17.30±0.385bc	<0.001

Within rows, means followed by same lowercase letters are not significantly different at P < 0.05; C, Control diet (0% BSF larvae meal and 100% fishmeal); D1, Diet 1 (25% BSF larvae meal and 75% fishmeal); D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal); D5, diet 5 (49 % BSF larvae meal, 49% fishmeal and baker's yeast at 2%)

In the current study, increasing inclusion rates of BSF larvae meals in the diets of the African catfish led to an increase in essential amino acids as shown in table 4.9. These results tally with a previous study which found that rearing Juvenile Barramundi using BSF larvae led to an increase in the amounts of essential amino acids with the increasing rates of BSF larave inclusion (Katya et al., 2017). The amino acid amounts realized in this study were higher than those recorded by Oellermann and Hecht. (2000) while comparing hybrid *C. gariepinus* and non-hybrid *C. gariepinus*. Peng et al. (2013) found that total amounts of essential amino acids in two types of natural farmed tuna ranged between 0.00% and 10.00% of the body weight in dry matter basis which is equivalent to what was realized from this study meaning that African catfish reared on BSF larvae meal results to a nutritious product for human consumption.

Essential amino acids are the most important group of amino acids as they are vital for body tissue regeneration (Mat et al., 1994; Institute of Medicine, 2002; Mariotti, 2016) and they can be dietary acquired through fish consumption. The findings of this study suggest that feeding African catfish with BSF larvae meal increases the concentration of essential amino acids and therefore the fish can be a very important source of the same. The present study indicated that the two species had all the essential amino acids. Leucine is credited with bone, muscle and skin regeneration while isoleucine has been shown to play vital roles in blood formation and energy metabolism (Heimann, 1982; Joint FAO/WHO/UNU, 2007; Witte et al., 2002).

Table 4.10: Recommended dietary requirements (mg/kg per day) of EAA as compared to the EAA in African catfish reared on different treatment diets

EAA	Children, (10–12 years)[1]	Adults[2]	EAA in Catfish carcass		
			D2	D3	D4
Histidine	not defined	8.00–12.00	22.93	31.92	32.34
Isoleucine	28.00	10.00	15.84	18.76	19.54
Leucine	42.00	14.00	18.09	21.45	22.74
Lysine	44.00	12.00	25.33	28.86	29.92
Methionine	22.00	13.00	30.95	31.11	33.03
Phenylalanine	22.00	14.00	20.81	28.09	28.63
Threonine	28.00	7.00	18.99	25.34	26.29
Valine	25.00	10.00	16.13	18.87	19.64

EAA, essential amino acids; D2, diet 2 (50% BSF larvae meal and 50% fishmeal); D3, diet 3 (75% BSF larvae meal and 25% fishmeal); D4, diet 4 (100% BSF larvae meal and 0% fishmeal);[1] Nakagawa et al., (1964); [2] FAO/WHO, 1973

Various studies have reported on the recommended dietary requirements of essential amino acids in mg/kg per day for children and adults are as is shown in the Table 4.10 (Institute of Medicine, 2002). The use of BSF larvae meal as a feed ingredient in African catfish will produce fish that meets most of the minimum requirements of dietary essential amino acids in human children and adults especially with 100% BSF larvae meal inclusion.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The BSFL meal utilized in this study had favorable nutritional composition with its CP of 47.40% DM whereas the fishmeal had a CP of 72.40% DM. The CP levels of the formulated fingerling diets attained the recommended nutritional requirements of 35-40% of catfish. The water quality parameters varied although they remained within the optimal ranges for rearing the African catfish.

The mortality was of the African catfish utilized in this study was below 2% which was negligible. Treatment diets D2 and D3 having 50% and 75 % BSF larvae meal respectively, had the best performances in terms of weight gain, length gain, feed conversion efficiency and standard growth rates. The proximate analysis on carcasses indicate that fish fed on D2 (50% BSFL meal) had the highest CP at 75.0% while D4 had the lowest at 65.2%. Treatment diets D2 and D4 had significantly ($P<0.05$) higher CP levels whereas diet D4 had significantly lower levels of CP.

Use of BSF larvae meal in this study gradually increased the carcass ether extract content with treatment D4 having the highest amount and the control diet C having the least. All the essential amino acids analyzed in this study were found to be higher in catfish fed BSF larvae meal up to 100% inclusion rates compared to African catfish reared on fishmeal which was the control diet. The results of this study indicate that BSF larvae meal is a viable African catfish fish feed protein source and it can be successfully used to replace fishmeal especially at 50% and

75% replacement rates without negatively affecting growth performance and carcass nutritional characteristics. The use of BSF larvae meal as a fish feed ingredient will enhance the essential amino acid levels of the African catfish thereby improving on human nutrition.

5.2 Conclusions

The study established that:

i. Black soldier fly larvae meal substitution rates of 50% and 75% were significant as compared to all the other treatment diets and increasing BSF larvae meal beyond this level didn't result to increased growth performance.

ii. The substitution of BSFL in the treatment diets didn't negatively affect the survival rates of the African catfish as the survival rates were above 98%.

iii. The carcass of African catfish reared on BSFL meal had higher quality in terms of:

a) Essential amino acid content which increased with increase in BSF larvae meal substitution.

b) Ash content

c) Crude protein content which was highest at 50% and 75% substitution rates and

d) Lipid content which increased with increased substitution of BSF larvae meal in the treatment diets.

5.3 Recommendations

i. The utilization of BSFL meal in African catfish grower diets is recommended.

ii. The utilization of BSFL meal at substitution rates 50% and 75% is recommended for better survival and enhanced growth performance especially for daily length and weight gains.

iii. Use of BSFL meal is also recommended for better quality fish in terms of the quality of protein: amino acids and crude protein levels.

5.4 Areas for further research

i. There is a need to evaluate the defatting of BSF larvae so as to enhance the nutritive composition and also reduce problems with larvae meal processing.

ii. Further study is required in order to evaluate/determine the utilization of BSFL meal at the finishing phase of the African catfish.

iii. Investigation of consumer acceptance of the African catfish reared on BSFL meal.

REFERENCES

Abdel-Tawwab, M., Abdel-Rahman, A. M., and Ismael, N. E. M. (2008). Evaluation of commercial live bakers' yeast, *Saccharomyces cerevisiae* as a growth and immunity promoter for fry nile tilapia, *Oreochromis niloticus* (L.) challenged in situ with *Aeromonas hydrophila*. Aquaculture, 280: 185–189. doi: 10.1016/j.aquaculture.2008.03.055.

Adebayo, O.T. and Alasoadura, T.A. (2001). Dietary protein requirements of clariid catfish hybrid, *Clarias gariepinus* x *Heterobranchus bidorsalis*, fry fed practical diets. *Journal of Applied Aquaculture*, 11(4): 93–101

Aderolu, A.Z., Lawal, M.O., Ali, T.O. and Aarode, O.O. (2011). Utilization of baker's yeast (*Saccharomyces cerevisiae*) in the diet of juvenile African catfish (*Clarias gariepinus*). Journal of Scientific Research and Development, 13: 19–27.

Adewolu, M.A. and Aro, O.O. (2009). Growth, feed utilization and haematology of *Clarias gariepinus* (Burchell, 1822) fingerlings fed diets containing different levels of vitamin C. *American Journal of Applied Sciences*, 6(9): 1675–1681.

Agunbiade, J.A., Adeyemi O.A., Ashiru, O.M., Awojobi, H.A., Taiwo, A.A., Oke, D.B. and Adekunmisi, A.A. (2007). Replacement of fishmeal with maggot meal in cassava-meal based layer diet. The Journal of Poultry Science, 44: 278–282.

Ahmed, N. and Diana, J. S. (2016). Does climate change matter for freshwater aquaculture in Bangladesh? Reg Environ Change, 16: 1659-1669 https://doi.org/10.1007/s10113-015-0899-6

Akinsanya, B. and Otubanjo, O.A. (2006). Helminth Parasites of *Clarias gariepinus* (Clariidae) in Lekki Lagoon, Lagos, Nigeria. International Journal of Tropical Biology, 54: 93-99.

Al-Qazzaz, M.F.A., Dahlan, I., Akit, H. and Lokman, H.I. (2016). Effect of using insect larvae meal as a complete protein source on quality and productivity characteristics of laying hens. Revista Brasileira de Zootecnia, 45: 518–523.

Alegbeleye, W.O., Obasa, S.O., Olude, O.O., Otubu, K. and Jimoh, W. (2002). Preliminary evaluation of the nutritive value of the variegated grasshopper (*Zonocerus variegatus* L.) for African catfish *Clarias gariepinus* (Burchell. 1822) fingerlings. Aquac Res, 43: 412–420.

Alexandratos, N. and Bruinsma, J. (2012). World Agriculture Towards 2030/2050: The 2012 Revision; ESAWorking paper. No. 12-03; FAO: Rome, Italy.

Ali, M.Z. (2001). Dietary protein and energy interactions in African catfish *Clarias gariepinus* (Burchell, 1822). Ph.D, Thesis, University of Stirling, pp. 273.

Alvarez, L. (2012). The role of black soldier fly, *Hermetia illucens* (L.) (Diptera: Stratiomyidae) in sustainable waste management in northern climates. PhD thesis, University of Windsor, Ontario, Canada. Available at: http://tinyurl.com/ybbu88lm.

Angel, R., Dhandu A.S., Applegate, T.J. and Christman, M. (2001). Phosphorus sparing effect of phytase, 25-hydroxycholecalciferol, and citric acid when fed to broiler chicks. *Poult. Sci.* 80, (Suppl. 1): 133-134.

Aniebo, A., Erondu, E. and Owen, O. (2009). Replacement of fish meal with maggot in African catfish (*Clarias gariepinus*) diets. Revista UDO Agrícola, 9: 666 – 671.

Antonio, S. L. (2015). Potential of pre-pupae meal of Black Soldier Fly (*Hermetia illucens*) as a fish meal substitute: effect on growth performance and digestibility in European Sea Bass (*Dicentrarchus labrax*). Master’s Thesis. University of Valencia.

AOAC. (1995). Official Methods of Analysis of AOAC International. Vol. I. Agriculture Chemicals; Contaminants, Drugs, 16th edn. AOAC International, Arlington,VA, USA.

Banks, I.J., Gibson, W.T. and Cameron, M.M. (2014). Growth rates of black soldier fly larvae fed on fresh human feces and their implication for improving sanitation. Tropical Medicine and International Health, 19: 14–22.

Banks, I.J. (2014). To assess the impact of black soldier fly (*Hermetia illucens*) larvae on faecal reduction in pit latrines. London School of Hygiene and Tropical Medicine Thesis, University of London. 10.17037/PUBS.01917781

Barragan-Fonseca, K. B., Dicke, M. and van Loon, J. J. A. (2017). Nutritional value of the black soldier fly (*Hermetia illucens L*.) and its suitability as animal feed: a review. J. Insects Food Feed 3: 105–120.

Barroso, F.G., de Haro, C., Sánchez-Muros, M.J., Venegas, E., Martínez-Sánchez, A. and Pérez-Bañón, C. (2014). The potential of various insect species for use as food for fish. Aquaculture, 422-423: 193–201.

Bava, L., Jucker, C., Gislon, G., Lupi, D., Savoldelli, S., Zucali, M. and Colombini, S. (2019). Rearing of *Hermetia illucens* on Different Organic By-Products: Influence on Growth, Waste Reduction, and Environmental Impact. Animals, 9: 289.

Belghit I, Liland NS, Waagbø R, Biancarosa I, Pelusio, Li Y, Krogdahl Å and Lock, E. (2018). Potential of insect-based diets for Atlantic salmon (Salmo salar). Aquaculture, 491:72-81.

Belghit, I., Liland, N.S., Gjesdal, P., Biancarosa, I., Menchetti, E., Li, Y., Waagbø, R., Krogdahl, Å. and Lock, E.J. (2019). Black soldier fly larvae meal can replace fish meal in diets of sea-water phase Atlantic salmon (*Salmo salar*). Aquaculture, 503: 609–619.

Biasato, I., Renna, M., Gai, F., Dabbou, S., Meneguz, M., Perona, G., Martinez, S., BarroetaLajusticia, A.C., Bergagna, S. and Sardi, L. (2019). Partially defatted black soldier fly larva meal inclusion in piglet diets: Effects on the growth performance, nutrient digestibility, blood profile, gut morphology and histological features. J. Anim. Sci. Biotechnol, 10: 12.

Bondari, K. and Sheppard, D.C. (1981). Soldier fly larvae as feed in commercial fish production. Aquaculture, 24: 103–109.

Bondari, K. and Sheppard, D.C. (1987). Soldier fly, *Hermetia illucens* L., larvae as feed for channel catfish, *Ictalurus punctatus* (Rafinesque), and blue tilapia, *Oreochromis aureus* (Steindachner). Aquaculture and Fisheries Management 18: 209 - 220.

Borgogno, M., Dinnella, C., Iaconisi, V., Fusi, R., Scarpaleggia, C., Schiavone, A., Monteleone, E., Gasco, L. and Parisi, G. (2017). Inclusion of *Hermetia illucens* larvae meal on rainbow trout (*Oncorhynchus mykiss*) feed: effect on sensory profile according to static and dynamic evaluations. J. Sci. Food Agric, 97: 3402 – 3411.

Cappellozza, S., Leonardi, M.G., Savoldelli, S., Carminati, D., Rizzolo, A., Cortellino, G., Terova, G., Moretto, E., Badaile, A. and Concheri, G. (2019). A first attempt to produce proteins from insects by means of a circular economy. Animals, 5: 278.

Cardinaletti, G., Randazzo, B., Messina, M., Zarantoniello, M., Giorgini, E., Zimbelli, A., Bruni, L., Parisi, G., Olivotto, I. and Tulli, F.J.A. (2019). Effects of graded dietary inclusion level of full-fat *Hermetia illucens* prepupae meal in practical diets for rainbow trout (*Oncorhynchus mykiss*). Animals, 9 (5): 251.

Chia, S.Y., Tanga, C.M., Khamis, F.M., Mohamed S.A., Salifu, D. and Sevgan, S. (2018). Threshold temperatures and thermal requirements of black soldier fly *Hermetia illucens*: Implications for mass production. PLoS ONE, 13(11): e0206097

Chia S.Y., Tanga C.M., Osuga I.M., Alaru A.O., Mwangi D.M, Githinji M., Sevgan S., Fiaboe K.K.M., Ekesi S., van Loon, J.J.A. and Dicke, M. (2019). Effect of dietary replacement of fishmeal by insect meal on growth performance, blood profiles and economics of growing pigs in Kenya Animals, 9: p. 705.

Cickova, H., Newton, G.L., Lacy, R.C. (2015). Kozánek M. The use of fly larvae for organic waste treatment. Waste Manag, 35: 68–80. pmid:25453313

Cohen, A.C. (2015). Insect Diets: Science and Technology, 2nd ed.; CRC Press: Boca Raton, FL, USA, p. 1– 473.

Collins, S. A., Overland, M., Skrede, A. and Drew, M. D. (2013). Effect of plant protein sources on growth rate in salmonids: Meta–analysis of dietary inclusion of soybean, pea and canola/rapeseed meals and protein concentrates. Aquaculture, 400: 85–100.

Commission Regulation (EU). (2017). 2017/893 of 24 May 2017 Amending Annexes I and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to Commission Regulation (EU) No 142/2011 as Regards the Provisions on Processed Animal Protein; Commission Regulation: Brussels, Belgium.

Cullere, M., Tasoniero, G., Giaccone, V., Miotti-Scapin, R., Claeys, E., De Smet, S. and Zotte, A.D. (2016). Black soldier fly as dietary protein source for broiler quails: Apparent digestibility, excreta microbial load, feed choice, performance, carcass and meat traits. Animal, 10: 1923–1930.

Cummins, V. C. Jr, Rawles, S. D., Thompson, K. R., Velasquez, A., Kobayashi, Y., Hager, J. and Webster, C. D. (2017). Evaluation of black soldier fly (*Hermetia illucens*) larvae meal as partial or total replacement of marine fish meal in practical diets for pacific white shrimp (*Litopenaeus vannamei*). Aquaculture, 473: 337–344. https://doi.org/10. 1016/j.aquaculture.2017.02.022

Dadebo, E., Aemro, D. and Tekle-Giorgis, Y. (2014). Food and feeding habits of the African catfish *Clarias gariepinus* (Burchell, 1822) (Pisces: Clariidae) in Lake Koka, Ethiopia. African Journal of Ecology, 52(4): 471-478.

Delgado, C.L., Wada, N., Rosegrant M.W., Meijer, S. and Ahmed, M. (2003). Outlook for fish to 2020: meeting global demand. In: A 2020 vision for food, agriculture, and the environment initiative. Int Food Policy Res Inst, Washington, DC, p 1 – 26.

Devic, E., Leschen, W., Murray, F. and Little, D. C. (2018). Growth performance, feed utilization and body composition of advanced nursing Nile tilapia (*Oreochromis niloticus*) fed diets containing Black Soldier Fly (*Hermetia illucens*) larvae meal. Aquacult Nutr, 24: 416 – 423. https://doi.org/10.1111/ anu.12573

De Marco, Martínez, M., Hernandez, S., Madrid, F., Gai, J., Rotolod, F., Belforti, L., Bergero, M., Katze, D., Dabbou, H., Kovitvadhi, S., Zoccarato, A., Gasco, I. and Schiavon, L. (2015). Nutritional value of two insect larval meals (*Tenebrio molitor* and *Hermetia illucens*) for broiler chickens: Apparent nutrient digestibility, apparent ileal amino acid digestibility and apparent metabolizable energy. Animal Feed Science and Technology, 209: 211 – 218.

Diener, S., Zubrügg, C. and Trockner, K. (2009). Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates. Waste Management and Research, 27: 603–610.

Diclaro, I. I., J.W. and Kaufman, P.E. (2009). Black soldier fly (*Hermetia illucens* Linnaeus*)* (Insecta: Diptera: Stratiomyidae). University of Florida, Gainesville, FL, USA. Available at: http://tinyurl.com/ y9a2qk93.

Djissou, A. S., Adjahouinou, D. C., Koshio, S. and Fiogbe, E. D. (2016). Complete replacement of fish meal by other animal protein sources on growth performance of *Clarias gariepinus* fingerlings. International Aquatic Research, 8(4): 333 – 341.

Dumas, A., Raggi, T., Barkhouse, J., Lewis, E. and Weltzien, E. (2018).The oil fraction and partly defatted meal of black soldier fly larvae (Hermetia illucens) affect differently growth performance, feed efficiency, nutrient deposition, blood glucose and lipid digestibility of rainbow trout (Oncorhynchus mykiss). Aquaculture, 492: 24–34.

Easton, M.D.L., Luszniak, D. and Von der Geest, E. (2002). Preliminary examination of contaminant loadings in farmed salmon, wild salmon and commercial salmon feed. Chemosphere, 46: 1053–1074.

El-Sayed, A-F.M. (1998). Total replacement of fishmeal with animal protein sources in Nile tilapia (*Oreochromis niloticus*) feeds. Aquac Res, 29: 275–280.

Erickson, M.C., Islam, M., Sheppard, C., Liao, J. and Doyle, M.P. (2004). Reduction of *Escherichia coli* O157:H7 and *Salmonella entericaserovar Enteritidis* in chicken manure by larvae of the black soldier fly. J. Food Protection, 67: 685 - 690.

Esteban, M., Cuesta, A. Ortuno, J. and Meseguer, J. (2001). Immunomodulatory effects of dietary intake of chitin on gilthead seabream (*Sparus aurata* L.) innate immune system. Fish Shellfish Immunol, 11: 303–315.

FAO/WHO. (1973). Energy and Protein Requirements. Report of a Joint FAO/WHO Ad Hoc Expert Committee. Technical Report Series No. 552; FAO Nutrition Meetings Report Series 52. World Health Organization, Rome. 118 pp.

FAO. (2006). The state of world fisheries and aquaculture FAO Fisheries and Aquaculture Department, Rome.

FAO. (2007). National Aquaculture Sector Overview- Kenya. FAO, Italy. 12p.

FAO. year book. (2008). Fishery and Aquaculture Statistics. Rome, 57p.

FAO. (2008). Report of the FAO Expert Workshop on Climate Change Implications for Fisheries and Aquaculture. In: *FAO Fisheries Report. No. 870.* Rome, Italy, 7–9 April 2008, p. 32.

FAO. (2012). The state of food and agriculture: Investing in agriculture for a better future. Rome: United Nations Food and Agriculture Organization. Available at: http://www.fao.org/docrep/017/i3028e/i3028e.pdf.

FAO. (2014). Fisheries and aquaculture. In: J. Graziano da Silva (Ed.). The state of world fisheries and aquaculture, opportunities and challenges (Vol. 4, pp. 40‑41). Rome , Italy: Office of Knowledge Exchange, Research and Extension FAO, Viale delle Terme di Caracalla.

FAO. (2016). The State of World Fisheries and Aquaculture. Contributing to food security and nutrition for all. Rome. p. 200.

FAO. (2020). Fisheries Department publications. Publications pages. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 21 January 2020. [Cited 13 March 2020].

Fasakin, E. A., Balogun, A. M. and Ajayi, O. O. (2003). Evaluation of full-fat and defatted maggot meals in the feeding of clariid catfish *Clarias gariepinus* fingerlings. Aquaculture Research, 34: 733-738.

Finke, M. D. (2007). Estimate of chitin in raw whole insects. Zoo Biology, 26: 105 - 115.

Finke, M. D. (2013). Complete Nutrient Content of Four Species of Feeder Insects. Zoo Biology, 32: 27–36.

Fiaboe, K. and Nakimbugwe, D. (2017). INSFEED: integrating insects in poultry and fish feed in Kenya and Uganda-final technical report.

Froese, R. and Pauly, D. (2016): Fishbase. Available from www. fishbase.org [cited 2020 January 15].

Gopalakannan, A. and Arul, V. (2006). Immunomodulatory effects of dietary intake of chitin, chitosan and levamisole on the immune system of *Cyprinus carpio* and control of *Aeromonas hydrophila* infection in ponds. Aquaculture, 255: 179‑187.

Gold, M., Tomberlin, J.K., Diener, S., Zurbrügg, C. and Mathys, A. (2018). Decomposition of bio-waste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review. Waste Manag, 82: 302–318.

Haasbroek, P. (2016). The use of *Hermetia illucens* and *Chrysomya chloropyga* larvae and prepupae meal in ruminant nutrition. Master's Thesis. Faculty of AgriSciences of Stellenbosch University.

Hale, O.M., (1973). Dried *Hermetia illucens* larvae (*Stratiomyidae*) as a feed additive for poultry. Journal of the Georgia Entomological Society, 8: 16 - 20.

Hamilton, M.L., Kuate, S.P., Brazier-Hicks, M., Caulfield, J.C., Rose, R. and Edwards, R. (2012). Elucidation of the biosynthesis of the di-C-glycosylflavone isoschaftoside, an allelopathic component from *Desmodium spp*. that inhibits *Striga spp*. development. Phytochemistry, 84: 169 – 176. pmid:22959223

Hasan, B., Putra, I., Suharman, I. and Iriani, D., (2016). Evaluation of salted trash fish as a protein source replacing fish meal in the diet for river catfish (*Hemibagrus nemurus*). AACL Bioflux, 9 (3): 647 – 656.

Heimann, W. (1982). Fundamentals of food chemistry. West Port, Connecticut, USA: Avi Pub. Co.

Helfrich, L. A. and Craig, S. (2002). Understanding Fish Nutrition, Feeds and Feeding. Virginia Cooperative Extension Service Publication.

Henry, M., Gasco, L., Piccolo, G. and Fountoulaki, E. (2015). Review on the use of insects in the diet of farmed fish: Past and future. Anim. Feed Sci. Technol, 203: 1–22.

Idowu, E. and Afolayan, E. (2013). The effects of supplementing of fish meal with maggots at varying levels in the diet of *Clarias gariepinus*. International Archive of Applied Sciences and Technology, 4: 41-47.

Institute of Medicine. (2002). Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients). Washington, DC: The National Academies Press.

IFIF. 2014. What is the global feed Industry? International Feed Industry Federation Factsheet. a8495aa37c863c4601415090026.pdf. International Feed Industry Federation (IFIF), Wiehl, Germany.

Jacobs, M.N., Covaci, A., Schepens, P. (2002). Investigation of selected persistent organic pollutants in farmed Atlantic salmon (*Salmo salar*), salmon aquaculture feed, and fish oil components of the feed. Environ. Sci. Technol. 36: 2797-2805.

JointFAO/WHO/UNU Expert Consultation. (2007). Protein and aminoacid requirements in human nutrition: report of a joint FAO/WHO/UNU expert consultation. World Health Organization, Geneva.

Józefiak, A., Nogales-Mérida, S., Rawski, M., Kierończyk, B. and Mazurkiewicz, J. (2019). Effects of insect diets on the gastrointestinal tract health and growth performance of Siberian sturgeon (*Acipenser baerii* Brandt, 1869). BMC Veterinary Research, 15(1): 348. DOI: 10.1186/s12917-019-2070-y.

Jucker, C., Erba, D., Leonardi, M.G., Lupi, D. and Savoldelli, S. (2017). Assessment of Vegetable and Fruit Substrates as Potential Rearing Media for Hermetia illucens (Diptera: Stratiomyidae) Larvae. Environ. Entomol, 46: 1415–1423.

Jucker, C., Lupi, D., Moore, C.D., Leonardi, M.G. and Savoldelli, S. (2020). Nutrient Recapture from Insect Farm Waste: Bioconversion with

Hermetia illucens (L.) (Diptera: Stratiomyidae). *Sustainability*, *12*, 362.

Katya, K., Borsra, M.Z.S., Ganesan, D., Kuppusamy, G., Herriman, M., Salter, A. and Azam, S.A. (2017). Efficacy of insect larval meal to replace fish meal in juvenile barramundi, *Lates calcarifer* reared in freshwater. IAR, 303-312.

Karapanagiotidis, I.T., Daskalopoulou, E., Vogiatzis, I., Rumbos, C., Mente, E. and Athanassious, C.G. (2014). Substitution of Fishmeal by Fly Hermetia illucens Prepupae Meal in the Diet of Gilthead Seabream (Sparus aurata). In Proceedings of the HydroMedit 2014, Volos, Greece.

Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N., Ekesi, S. (2015). African edible insects for food and feed: Inventory, diversity, commonalities and contribution to food security. J. Insects Food Feed, 1: 103–119.

Keyombe, J. L., Waithaka, E., Obegi, B. (2015): Length-weight relationship and condition factor of *Clarias gariepinus* in Lake Naivasha, Kenya. International Journal of Fisheries and Aquatic Studies, 2: 382-385.

Kobeiusy, M.A. and Hussein S.Y. (1995). Influence of Dietary Live Yeast on Growth Performance and Some Blood Constituents in *Oreochromis niloticus*. Proceedings of 5th science conference Animal Nutrition, Ismailia, Egypt, pp. 417-425.

Kristofersson, D. and Anderson, J.L. (2006). Is there a relationship between fisheries and farming? Inter-dependence of fisheries, animal production and aquaculture. Marine Policy, 30: 721–725.

Kroeckel, S., Harjes A-G.E., Roth, I., Katz, H., Wuertz, S. Susenbeth, A. and Schulz, C. (2012). When a turbot catches a fly: Evaluation of a pre-pupae meal of the Black Soldier Fly (*Hermetia illucens*) as fish meal substitute — Growth performance and chitin degradation in juvenile turbot (*Psetta maxima*). Aquaculture, 364-365: 345-352.

Lalander, C.H., Fidjeland, J., Diener, S., Erikson, S. and Vinneras, B. (2015). High waste-to-biomass conversion and efficient *Salmonella spp* reduction using Black Soldier Fly for waste recycling. Agron Sustain Dev, 35: 261 - 271.

Leiber, F., Gelencsér, T., Stamer, A., Amsler, Z., Wohlfahrt, J., Früh, B. and Maurer, V. (2017). Insect and legume-based protein sources to replace soybean cake in an organic broiler diet: Effects on growth performance and physical meat quality. Renewable Agriculture and Food Systems, 32(1): 21 - 27. https://doi:10.1017/S1742170515000496

Leong, S.Y., Kutty, S.R.M., Malakahmad, A. and Tan, C.K. (2016). Feasibility study of biodiesel production using lipids of *Hermetia illucens* larva fed with organic waste. Waste Manag, 47: 84 – 90.

Liu, X., Chen, X., Wang, H., Yang, Q., ur Rehman, K. and Li, W. (2017). Dynamic changes of nutrient composition throughout the entire life cycle of black soldier fly. PLoS ONE, 12(8): e0182601. https://doi.org/10.1371/journal.pone.0182601

Liu, Q.L., Tomberlin, J.K., Brady, J.A., Sanford, M.R. and Yu, Z.N. (2008). Black soldier fly (Diptera: Stratiomyidae) larvae reduce *Escherichia coli* in dairy manure. Environ. Entomol, 37: 1525–1530.

Li, Q, Zheng, L., Qiu, N., Cai, H., Tomberlin, J.K. and Yu, Z. (2011a). Bioconversion of dairy manure by black soldier fly (Diptera: Stratiomyidae) for biodiesel and sugar production. Waste Management, 31: 1316 – 1320.

Li, Q., Zheng, L.Y., Cai, H., Garza, E., Yu, Z.N. and Zhou, S.D. (2011b) From organic waste to biodiesel: black soldier fly, *Hermetia illucens*, makes it feasible. Fuel, 90: 1545 – 1548.

Lim, P. K., Boey, P. L. and Ng, W. K. (2000). Dietary palm oil level affects growth performance, protein retention and tissue vitamin E concentration of African catfish, *Clarias gariepinus*. Aquaculture, 202: 101–112.

Liland, N.S., Biancarosa, I., Araujo, P. and Biemans, D. (2017). Modulation of nutrient composition of black soldier fly (*Hermetia illucens*) larvae by feeding seaweed-enriched media. PLoS One, 12 (8): e0183188. http://dx.doi.org/10.1371/journal.pone. 0183188.

Lock, E. R., Arsiwalla, T. and Waagbø, R. (2015). Insect larvae meal as an alternative source of nutrients in the diet of Atlantic salmon (*Salmon salar*) postsmolt. *Aquaculture Nutrition*, 22: 1202‑1213.

Lock, E.J., Biancarosa, I. and Gasco, L. (2018). Insects as raw materials in compound feed for aquaculture. In Edible Insects in Sustainable Food Systems; Halloran, A., Flore, R., Vantomme, P., Roos, N., Eds.; Springer International Publishing: Cham, Switzerland, p. 263 – 276.

Lunger, A. N., Craig, S. R., and McLean, E. (2006). Replacement of fish meal in cobia (*Rachycentron canadum*) diets using an organically certified protein. Aquaculture, vol. 257, no. 1–4: 393 – 399.

Magalhães, R., Sánchez-López, A., Leal, R.S. and Martínez-Llorens, S. (2017). Black soldier fly (Hermetia illucens) pre-pupae meal as a fish meal replacement in diets for European seabass (*Dicentrarchus labrax*). Aquaculture 476, 79–85. http://dx.doi.org/ 10.1016/j.aquaculture.2017.04.021.

Makkar, H.P.S., G. Tran, V. Heuzé, and P. Ankers. (2014). Review: State-of-the-art on use of insects as animal feed. Anim. Feed Sci. Technol, 197: 1 – 33.

Manoppo, H. and Magdalena, E.F. (2016). The use of baker's yeast to promote growth of carp (*Cyprinus carpio L*). International Journal of

PharmTech Research CODEN (USA): IJPRIF, ISSN: 0974-4304, ISSN(Online): 2455-9563 Vol.9: 415-420.

Manzano-Agugliaro, F., Sanchez-Muros, M.J., Barroso, F.G., Martínez-Sánchez, A., Rojo, S. and Pérez-Bañón, C. (2012). Insects for biodiesel production. Renew. Sustain. Energy Rev, 16: 3744 – 3753.

Marono, S., Piccolo, G., Loponte, R., Di Meo, C., Attia, Y. A., Nizza, A. and Bovera F. (2015). *In Vitro* Crude Protein Digestibility of *Tenebrio Molitor* and *Hermetia Illucens* Insect Meals and its Correlation with Chemical Composition Traits, Italian Journal of Animal Science, 14: 3. https://DOI: 10.4081/ijas.2015.3889

Mariotti, F., Tomé, D., Mirand, P.P. (2008). Converting nitrogen into protein - Beyond 6.25 and Jones' factors. Crit. Rev. Food Sci. Nutr, 48: 177–184.

Mariotti, F. (2016). Protein Intake throughout Life and Current Dietary Recommendations. 10.1016/B978-0-12-802167-5.00002-5.

Mat Jais A.M., McCulloh, R. and Croft, K. (1994). Fatty acid and amino acid composition in haruan as a potential role in wound healing. General Pharmacology 25: 947 - 950.

Maurer, V., Holinger, M., Amsler, Z., Früh, B., Wohlfahrt, J., Stamer, A. and Leiber, F. (2015). Replacement of soybean cake by *Hermetia illucens* meal in diets for layers. J. Insects Food Feed, 2: 83 – 90.

Meneguz, M., Schiavone, A., Gai, F., Dama, A., Lussiana, C., Renna, M. and Gasco, L. (2018). Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (*Hermetia illucens*) larvae. Sci. Food Agric. 98: 5776 – 5784. https://doi.org/10.1002/jsfa.9127.

Médale, F., Le Boucher, R., Dupont-Nivet, M., Quillet, E., Aubin, J. and Panserat, S. (2013). Plant-based foods for farmed fish. Animal productions, 26: 303- 316

Mona, M.H, Alm-Eldeen, A.A., Elgayar, E.E., Heneish A.M. and El-feky, M.M.M. (2015). Evaluation the Effect of Local and Imported Yeasts as Supplementary Food on the African Catfish (Clarias gariepinus) in Egypt. J Aquac Mar Biol, 2(3): 00024. https://DOI: 10.15406/jamb.2015.02.00024

Munguti, J.M., Musa, S., Orina, P.S., Kyule, D.N., Opiyo, M.A., Karisa, H.C. and Ogello, E.O. (2014). An overview of current status of Kenyan fish feed industry and feed management practices, challenges and opportunities. International Journal of Fisheries and Aquatic Studies, 1(6): 128 - 137.

Murthy, H. S. and D. M. Gatlin. (2006). Sulfur amino acid utilization: important element of fish nutrition varies by species. Global Aquaculture Advocate, vol. 9, pp. 68 – 69.

Musundire, R., Osuga, I. M., Cheseto, X., Irungu, J. and Torto, B. (2016). Aflatoxin Contamination Detected in Nutrient and Anti-Oxidant Rich Edible Stink Bug Stored in Recycled Grain Containers. PLoS ONE 11, https://doi.org/10.1371/journal.pone.0145914

Muzinic, L.A, Thompson, K.R., Metts, L.S., Dasgupta, S. and Webster, C.D. (2006). Use of turkey meal as partial and total replacement of fish meal in practical diets for sunshine bass (*Morone chrysops* × *Morone saxatilis*) grown in tanks. Aquacult Nutr, 12: 71–81 https://doi.org/10.1111/j.1365-2095.2006.00387.x

Mwaniki, Z., Neijat, M. and Kiarie, E. (2018). Egg production and quality responses of adding up to 7.5% defatted black soldier fly larvae meal in a corn–soybean meal diet fed to Shaver White Leghorns from wk 19 to 27 of age, Poultry Science, Volume 97, Issue 8: 2829–2835, https://doi.org/10.3382/ps/pey118

Myers, H.M., Tomberlin, J.K., Lambert, B.D. and Kattes, D. (2008). Development of black soldier fly (Diptera: *Stratiomyidae*) larvae fed dairy manure. Environ. Entomol, 37: 11–15.

Na-Nakorn, U. and Brummett, R.E. (2009). Use and exchange of aquatic genetic resources for food and aquaculture: *Clarias gariepinus*. Reviews in Aquaculture, 1: 214–223

Nakagawa, I., T. Takahashi, T. Suzuki, and K. Kobayashi. (1964). Amino acid requirements of children: nitrogen balance at the minimum level of essential amino acids. J. Nutr, 83: 115–118. [PubMed]

Nelson, J. S. (2006). Fishes of the world. New Jersey (USA), John Wiley and Sons. P. 601.

Newton, G. L., Booram, C. V., Barker, R. W. and Hale, O. M. (1977). Dried *Hermetia illucens* larvae meal as a supplement for swine. J. Anim. Sci, 44: 395-400

Newton, L., Sheppard, C., Watson D.W., Burtle, G. and Dove, R. (2005a): Using the Black Soldier Fly, *Hermetia illucens*, as a Value-added Tool for the Management of Swine Manure. Animal and Poultry Waste Management Center, North Carolina State University, Raleigh, NC, p. 17.

Newton, G.L., Sheppard, D.C., Watson, D.W., Burtle, G., Dove, C.R., Tomberlin, J.K. and Thelen E.E. (2005b).The black soldier fly, *Hermetia illucens*, as a manure management/resource recovery tool. In Proc. Symp. on the State of the Science of Animal Manure and Waste Management, San Antonio, TX, USA, January 5–7, 2005. p. 2–17.

Ng, W. K., Liew, F. L., Ang, L. P. and Wong, K. W. (2001). Potential of mealworm (*Tenebrio molitor*) as an alternative protein source in practical diets for African catfish, *Clarias gariepinus*. Aquaculture Research, 32: 273–280.

Ngugi, C.C., Bowman, J.R. and Omollo B.D. (2007). A new guide to fish farming in Kenya. ACRSP. Oregon University, Oregon, USA. p95.

Nguyen, T.T.X., Tomberlin, J.K. and Vanlaerhoven, S. (2015). Ability of black soldier fly (Diptera: *Stratiomyidae*) larvae to recycle food waste. Environ Entomol, 44(2): 406–10. pmid:26313195

Nogales-Mérida, S., Gobbi, P., Józefiak, D., Mazurkiewicz, J., Dudek, K., Rawski, M., Kierónczyk, B. and Józefiak, A. (2018) Insect meals in fish nutrition. *Reviews in Aquaculture*. https://doi.org/10.1111/raq.12281

NRC (National Research Council). (2011). *Nutrient Requirements of Fish and Shrimp*. Washington DC: National Academy of Sciences, National Academies Press.

Nyina-wamwiza, L., Wathelet, B. and Kestemont, P. (2007). Potential of local agricultural by-products for the rearing of African catfish, *Clarias gariepinus* in Rwanda: Effects on growth feed utilization and body composition. Aquaculture Research, 38: 206–214.

Oellermann L.K. and Hecht T. (2000). Composition of the fillet yield, protein content and amino acid profile of *Clarias gariepinus* and the *C. gariepinus X H. longifilis* hybrid. Aquac Res, 31: 553-556.

Ogello E. O and Opiyo M. A. (2011). A Review of the African Catfish Production in Kenya: Opportunities and Challenges. In: Samaki News:

Aquaculture Development in Kenya towards Food Security, Poverty Alleviation and Wealth Creation. Vol. 7, No. 1: p. 18-20.

Ogunji, J. O., Kloas, W., Wirth, M., Schulz, C. and Rennert, B. (2008). Housefly maggot meal (magmeal) as a protein source for *Oreochromis niloticus* (Linn.). Asian Fisheries Science, 21: 319-331

Ogunji, J. O. and Awoke, J. (2017). Effect of environmental regulated water temperature variations on survival, growth performance and haematology of African catfish, *Clarias gariepinus*. Our Nature, 15(1-2): 26-33.

Olsen, R.L., Hasan M.R. (2012). A limited supply of fishmeal: Impact on future increases in global aquaculture production. Trends in Food Science Technology, 27: 120 –128.

Onsongo, V. O., Osuga, I. M., Gachuiri, C. K., Wachira, A. M., Miano, D. M., Tanga, C. M., Ekesi, S., Nakimbugwe, D., and Fiaboe, K. K. M. (2018). Insects for Income Generation Through Animal Feed: Effect of Dietary Replacement of Soybean and Fish Meal With Black Soldier Fly Meal on Broiler Growth and Economic Performance. Journal of Economic Entomology, XX(X): 1–8.

Oz´orio, R.O. A., Portz, L., Borghesi, R. and Cyrino, J. E. P. (2012). Effects of dietary yeast (*Saccharomyces cerevisia*) supplementation in practical diets of tilapia (*Oreochromis niloticus*), Animals, vol. 2, no. 1: 16–24.

Pantazis, P.A. (2005). Protein to energy ratios in African catfish fed purified diets: is *Clarias gariepinus* an ordinary carnivore. Archives of Polish Fisheries, 13: 157-170.

Paulk, A. (2006). Proprioceptive encoding of head position in the black soldier fly, *Hermetia illucens* (L.) (Stratiomyidae). J Exp Biol, 209: 3913–3924. pmid:16985207

Peng, S., Chen, C., Shi, Z. and Wang, L. (2013). Amino acid and fatty acid composition of the muscle tissue of yellowfin tuna (Thunnus albacares) and bigeye tuna (*Thunnus obesus*). J. Food Nutr. Res. 1:42–45. http://dx.doi.org/10.12691/jfnr-1-4-2.

Ponzoni, R.W. and Nguyen, N.H. (2008). Proceedings of a Workshop on the Development of a Genetic Improvement Program for African catfish *Clarias gariepinus*. In: World Fish Center Conference Proceedings Number 1889.World Fish Center, Penang, Malaysia p. 130.

Ramachandran S., and Ray A.K. (2007). Nutritional evaluation of fermented black gram (Phaseolus mungo) seed meal in compound diets for rohu, Labeo rohita(Hamilton), fingerlings. J. Appl. Ichthyol, 23: 74-79 https://doi.org/10.1111/j.1439-0426.2006.00772.x

Rana, K.J., Siriwardena, S. and Hasan, M.R. (2009). Impact of rising feed ingredient prices on aquafeeds and aquaculture production. FAO

Fisheries and Aquaculture Technical Paper. No. 541. Rome, FAO, p 63.

Renna, M., Schiavone, A., Gai, F., Dabbou, S., Lussiana, C., Malfatto, V., Prearo, M., Capucchio, M., Biasato, I. and Biasibetti, E. (2017). Evaluation of the suitability of a partially defatted black soldier fly (*Hermetia illucens* L.) larvae meal as ingredient for rainbow trout (*Oncorhynchus mykiss* Walbaum) diets. J. Anim. Sci. Biotechnol, 8.

Rimoldi, S., Gini, E., Iannini, F., Gasco, L. and Terova G. (2019). The Effects of Dietary Insect Meal from *Hermetia illucens* Prepupae on Autochthonous Gut Microbiota of Rainbow Trout (*Oncorhynchus mykiss*). Animals: an Open Access Journal from Mdpi. 9(4) DOI: 10.3390/ani9040143.

Robinson, E. H. and Li, M. H. (2010). Channel catfish, *Ictalurus punctatus*, size and feed conversion ratio. Journal of the World Aquaculture Society, 41(5): 829-833.

Robinson, E. H., Li, M. H. and Manning, B. B. (2001). A practical guide to nutrition, feeds, and feeding of catfish (second revision), 44. Agricultural Communications Bulletin 1113. Division of Agriculture, Forestry, and Veterinary Medicine, Mississippi State University.

Rumpold, B.A. and Schlüter, O.K. (2013). Potential and challenges of insects as an innovative source for food and feed production. Innov. Food Sci. Emerg. Technol, 17: 1–11.

Rumsey, G.L., Hughes, S.G., and Kinsella, J.L. (1990). Use of dietary yeast *Saccharomyces cerevisia*e nitrogen by lake trout. Aquacult, 21: 205-209.

Rumsey, G.L., Kinsella, J.E., Shetty, K.J. and Hughes, S.G. (1991). Effect of high dietary concentrations of brewer's dried yeast on growth performance and liver uricase in rainbow trout. Anim. Feed Sci. Technol., 33: 177-183.

Rust, M. B. (2002). Nutritional physiology. In J. E. Halver, and R. W. Hardy (Eds.) New York, NY, USA: The Academic Press. Fish nutrition, 3: 368‑446.

Salnur, S., Gultepe N. and Hossu, B. (2009). Replacement of fish meal by yeast (*Saccharomyces cerevisiae*): effects on digestibility and blood parameters for gilthead sea bream (*Sparus aurata*). Journal of Animal and Veterinary Advances, vol. 8, no. (12): 2557–2561.

Sangduan, C. (2018). Skincare Product Containing Hermetia illucens Extract. U.S. Patent 15/981,689, 13 September.

Sánchez-Muros, M.J., Barroso, F.G. and Manzano-Agugliaro, F. (2014) Insect meal as renewable source of food for animal feeding: A review. J. Clean. Prod, 65: 16–27.

Sanchez-Muros, M.J.S., De Haro, C., Sanz A., Villareces, S. and Barroso, F.G. (2015). Nutritional evaluation of *Tenebrio molitor* meal as fishmeal substitute for Tilapia (*Oreochromis niloticus*) diet. Aquac Nutr, 22(5): 943–955.

Schiavone, A., Cullere, M., De Marco, M., Meneguz, M., Biasato, I., Bergagna, S., Dezzutto, D., Gai, F., Dabbou, S. and Gasco, L. (2017). Partial or total replacement of soybean oil by black soldier fly larvae (*Hermetia illucens* L.) fat in broiler diets: Effect on growth performances, feed-choice, blood traits, carcass characteristics and meat quality. Ital. J. Anim. Sci, 16: 93–100.

Sealey, W. M., Gaylord, T. G., Barrows, F. T., Tomberlin, J. K., McGuire, M. A.,and Ross, C. (2011). Sensory analysis of rainbow trout, *Oncorhynchus mykiss*, fed enriched black soldier fly prepupae, *Hermetia illucens*. Journal of the World Aquaculture Society, 42: 34–45.

Secci, G., Bovera, F., Nizza, S., Baronti, N., Gasco, L., Conte, G. and Parisi, G. (2018). Quality of eggs from Lohmann Brown classic laying hens fed black soldier fly meal as substitute for soybean. Animal, http://dx.doi.org/10.1017/S1751731117003603.

Sheppard, C., Newton, G. L., Thompson, S. A. and Savage, S. (1994). A value added manure management system using the black soldier flies. Bioresource Technology, 50: 275-279.

Shiau, S.Y. and Yu, Y.P. (1999). Dietary supplementation of chitin and chitosan depresses growth in tilapia, *Oreochromis niloticus * O. aureus*. Aquaculture, 179: 439–446.

Shitote, Z., Wakhungu, J. and China, S. (2012). Challenges Facing Fish Farming Development in Western Kenya. Greener Journal of Agricultural Sciences ISSN: 2276-7770 Vol. 3 (5): 305-311.

Skelton, P. (2001). A complete guide to the freshwater fishes of Southern Africa. 2[ed]. Struik Publishers, Cape Town, p. 388.

Smith, J.L, Opekun, A.R, Larkai, E. and Graham, D.Y. (1989). Sensitivity of the esophageal mucosa to pH in gastroesophageal reflux disease. Gastroenterology, 96: 683–689.

Smetana, S., Palanisamy, M., Mathys, A. and Heinz, V. (2016). Sustainability of insect use for feed and food: Life cycle assessment perspective. J. Clean. Prod, 137: 741–751.

Sogari, G., Amato, M., Biasato, I., Chiesa, S. and Gasco, L. (2019). The Potential role of insects as feed: A Multi-Perspective Review. Animals, 9: 119.

Sogbesan, A. O. and Ugwumba, A. A. A. (2008). Nutritional evaluation of termite (*Macrotermes subhyalinus*) meal as animal protein supplements in the diets of *Heterobranchus longifilis* (Valenciennes, 1840) fingerlings. Turkish Journal of Fisheries and Aquatic Sciences, 8: 149–157.

Soliman, N.F., Yacout, D.M.M. and Hassaan, M.A. (2017). Responsible fishmeal consumption and alternatives in the face of climate changes, International Journal of Marine Science, 7(15): 130-140. https:// (doi: 10.5376/ijms.2017.07.0015)

Solomon, S.G., Ataguba. G.A. and Abeje. A. (2011). Water stability and floatation test of fish pellets using local starch sources and yeast (*saccahramyces cerevisae*). International Journal of Latest Trends in Agricultural Food Science, 1(1): 1-5.

Stadtlander, T., Stamer, A., Buser, A., Wohlfahrt, J., Leiber, F. and Sandrock, C. (2017). *Hermetia illucens* meal as fishmeal replacement for rainbow trout on farm. J. Insects Food Feed, 3: 165 - 175. https://doi.org/10.3920/JIFF2016.0056.

Steinfeld, H., Gerber, P., Wassenaar, T.D., Castel, V. and de Haan, C. (2006). Livestock's long shadow: environmental issues and options. The Livestock EaDI, editor. Rome: FAO.

Stamer, A., Wesselss, S., Neidigk, R. and Hoerstgen-Schwark, G. (2014). Black Soldier Fly (*Hermetia illucens*) larvae-meal as an example for a new feed ingredients' class in aquaculture diets. In: Proceedings of the 4th ISOFAR Scientific Conference. "Building Organic Bridges", at the Organic World Congress. Istanbul, Turkey, p. 1043–1046.

Summerfelt, R. C. (2000). Water quality considerations for aquaculture. Aquaculture Network Information Centre. http://aquanics.org.

Surendra, K.C., Olivier, R., Tomberlin, J.K., Jha, R. and Khanal, S.K. (2016). Bioconversion of organic wastes into biodiesel and animal feed via insect farming. Renew. Energ, 98: 197–202.

St-Hilaire, S., Sheppard, C., Tomberlin, J. K., Irving, S., Newton, L., McGuire, M. A. and Sealey, W. (2007a). Fly prepupae as a feedstuff for rainbow trout, *Oncorhynchus mykiss*. Journal of the World Aquaculture Society, 38: 59–67.

St-Hilaire, S., Sheppard, C., Tomberlin, J. K., Irving, S., Newton, L., McGuire, M. A. and Sealey, W. (2007b). Fish Offal Recycling by the Black Soldier Fly Produces a Foodstuff High in Omega-3 Fatty Acids. J World Aquaculture Soc Journal of the World Aquaculture Society, 38: 2

Spranghers, T., Ottoboni, M., Klootwijk, C., Ovyn, A., Deboosere, S., De Meulenaer, B. and De Smet, S. (2016). Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates. Journal of the Science of Food and Agricultural. http://dx.doi.org/10.1002/jsfa.8081.

Tacon, A.G.J. and Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture, 285: 146–158.

Tacon, A.G.J. and Metian, M. (2009). Fishing for aquaculture: Nonfood use of small pelagic forage fish, a global perspective. Rev Fish Sci, 17: 305–317.

Tinder, A.C., Puckett, R.T., Turner, N.D., Cammack, J.A. and Tomberlin, J.K. (2017). Bioconversion of sorghum and cowpea by black soldier fly (Hermetia illucens (L.) larvae for alternative protein production. J. Insects Food Feed, 3: 121–130.

Tomberlin, J., Van Huis, A., Benbow, M., Jordan, H., Astuti, D., Azzollini, D., Banks, I., Bava, V., Borgemeister, C. and Cammack, J. (2015). Protecting the environment through insect farming as a means to produce protein for use as livestock, poultry, and aquaculture feed. J. Insects Food Feed, 1: 307–309.

Tomberlin, J.K. and Sheppard, D.C. (2002). Factors influencing mating and oviposition of black soldier flies (Diptera: Stratiomyidae) in a colony. J Entomol Sci, 37: 345–352.

Tran, G., Heuzè, V. and Makkar, P.S. (2015). Insects in fish diets. Anim. Front. 5: 37–44.

Tukey, J. W. (1991). The Philosophy of Multiple Comparisons. Statistical Science, 6(1): 98 - 116.

United Nations. (2013). Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2012 Revision, Highlights and Advance Tables; Working Paper No.

ESA/P/WP.228; Department of Economic and Social Affairs, Population Division: New York, NY, USA.

Ur Rehman, K., Rehman, A., Cai, M., Zheng, L., Xiao, X., Somroo, A.A., Aziz, A., Wang, H., Li,W. and Yu, Z. (2017). Conversion of mixtures of dairy manure and soybean curd residue by black soldier fly larvae (*Hermetia illucens* L.). J. Clean. Prod, 154: 366–373.

Van Huis, A. (2013). Potential of insects as food and feed in assuring food security. Annu. Rev. Entomol, 58: 563–583.

Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G. and Vantomme, P. (2013). Edible Insects: Future Prospects for Food and Feed Security; Forestry Paper 171; FAO: Rome, Italy.

Vargas, A.A., Randazzo, B., Foddai, M., Sanchini, L., Truzzi, C., Giorgini, E., Gasco, L. and Olivotto, I. (2019). Insect meal based diets for clownfish: Biometric, histological, spectroscopic, biochemical and molecular implications. Aquaculture, 498: 1–11. https://doi: 10.1016/j.aquaculture.2018.08.018.

Vargas, A.A., Randazzo, B., Riolo, P., Truzzi, C., Gioacchini, G., Giorgini, E.; Loreto, N., Ruschioni, S., Zarantoniello, M. and Antonucci, M. (2018). Rearing zebrafish on black soldier fly (*Hermetia illucens*): Biometric, histological, spectroscopic, biochemical, and molecular implications. Zebrafish, 15: 404–419.

Veldkamp, T., Van Duinkerken, G., Van Huis, A., Lakemond, C.M.M., Ottevanger, E., Bosch, G. and Van Boekel, M.A.J.S. (2012). Insects as a Sustainable Feed Ingredient in Pig and Poultry Diets—A Feasibility Study; Report 638; Wageningen UR Livestock Research: Wageningen, The Netherlands. Available online: http://library.wur.nl/WebQuery/wurpubs/fulltext/234247

Wang, Y.S. and Shelomi, M. (2017). Review of Black Soldier Fly (*Hermetia illucens*) as Animal Feed and Human Food. Foods, 6: 91.

Weyl, O. L. F., Daga, V. S., Ellender, B. R. and Vitulet, J. R. S. (2016). A review of *Clarias gariepinus* invasions in Brazil and South Africa. Journal of Fish Biology, 89: 386-402.

Widjastuti, T., Wiradimadja, R. and Rusmana, D. (2014). The Effect of Substitution Of Fish Meal By Black Soldier Fly (*Hermetia Illucens*) Maggot Meal In The Diet On Production Performance Of Quail *(Coturnix Coturnix Japonica)* Scientific Papers. Series D. Animal Science. Vol. LVII.

Wen, Y. H., Cao, J. M., Huang, Y. H., Wang, G. X., Mo, W. Y., Sun, Z. W. and Liu, X. L. (2013). Effects of fish meal replacement by maggot meal on growth performance, body composition and plasma biochemical indexes of juvenile yellow catfish (*Peltobagrus fulvidraco*). Chinese Journal of Animal Nutrition, 25: 171–181.

Witte, M.B., Thornton F.J., Tantry U and Barbul, A. (2002). L- Arginine supplementation enhances diabetic wound healing; involvement of the nitric oxide synthase and arginase pathways. Metabolism, 51(10): 1269-1273.

Wu, G., Saoud, I.P., Miller, C. & Davis, D.A. (2004). The effect of feeding regimen on mixed-size pond-grown channel catfish, *Ictalurus punctatus*. J. Appl. Aquacult, 15: 115–125.

Xiao, X., Jin, P., Zheng, L., Cai, M., Yu, Z., Yu, J. and Zhang, J. (2018). Effects of black soldier fly (*Hermetia illucens*) larvae meal protein as a fishmeal replacement on the growth and immune index of yellow catfish (*Pelteobagrus fulvidraco*). Aquacult Res, 49: 1569-1577.

Yu, D. H., Gong, S. Y., Yuan, Y. C., Luo, Z., Lin, Y. C. and Li, Q. (2013). Effect of partial replacement of fish meal with soybean meal and feeding frequency on growth, feed utilization and body composition of juvenile Chinese sucker (*Myxocyprinus asiaticus* B). Aquaculture Research, 44: 388–394. https://doi.org/10.1111/j.1365-2109.2011.03043.x

Zarantoniello, M., Bruni, L., Randazzo, B., Vargas, A., Gioacchini, G., Truzzi, C., Annibaldi, A., Riolo, P., Parisi, G. and Cardinaletti, G. (2018). Partial dietary inclusion of *Hermetia illucens* (black soldier fly) full-fat prepupae in Zebrafish feed: Biometric, histological, biochemical, and molecular implications. Zebrafish, 15: 519–532.

Zarantoniello, M., Randazzo, B., Truzzi, C., Giorgini, E., Marcellucci, C., Vargas-Abúndez, J.A., Zimbelli, A., Annibaldi, A., Parisi, G., Tulli, F., Riolo, P. and Olivotto I. (2019). A six-month study on black soldier fly (*Hermetia illucens*) based diets in zebrafish Sci. Rep., 9 (8598): 1-12. https://10.1038/s41598-019-45172-5p

Zehra, S. and Khan, M. A. (2016). Total sulphur amino acid requirement and maximum cysteine replacement value for methionine for fingerling *Catla catla* (Hamilton). *Aquaculture Research*, vol. 47, no. 1, pp. 304–317.

Zhang, A.W., Lee, B.D., Lee S.K., Lee K.W., An G.H., Song, K.B. and Lee C.H. (2005). Effects of Yeast (*Saccharomyces cerevisiae*) Cell Components on Growth Performance, Meat Quality, and Ileal Mucosa Development of Broiler Chicks. J. Poult. Sci, 84: 1015–1021.

Zheng, L., Li, Q., Zhang, J. and Yu, Z. (2012). Double the biodiesel yield: Rearing black soldier fly larvae, *Hermetia illucens*, on solid residual fraction of restaurant waste after grease extraction for biodiesel production. Renew. Energ, 41: 75–79.

Zhou, J.S., Liu, S.S., Ji, H. and Yu, H.B. (2018). Effect of replacing dietary fish meal with black soldier fly larvae meal on growth and fatty acid composition of Jian carp (*Cyprinus carpio var*. Jian). Aquacult Nutr, 24: 424–433. https://doi.org/10.1111/anu.12574

Zieli´nska, E., Baraniak, B., Kara´s, M., Rybczy´nska, K. and Jakubczyk, A. (2015). Selected species of edible insects as a source of nutrient composition. Food Res. Int, 77: 460–466.

Zuidhof, M.J., Molnar, C.L., Morley, F.M., Wray, T.L., Robinson, F.E., Khan, B.A. and Goonewardene, L.A. (2003). Nutritive value of house flies larvae as a feed supplement for turkey poults. Anim. Feed Sci. Tech, 105: 225-230.

***** http://www.fao.org/fishery/culturedspecies/Clarias_gariepinus/en. Accessed: 3 October 2019.

APPENDICES

Appendix 1: Pond preparation and harper cage installation

Appendix 2: Completed and stocked cages in the experimental pond at the start of the study.

Appendix 3: Sample catfish during data collection

Appendix 4: Sample of a post-fingering catfish during the study.