



**JIMMA UNIVERSITY**  
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**DEPARTMENT OF BIOLOGY**

**Evaluating the Inclusion of Black Soldier Fly Larvae in the Practical Diets  
of African Catfish (*Clarias gariepinus*)**

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## **Declaration**

I, Mekash Yirga Beshir, declare that the MSc research entitled “Evaluating the Effectiveness of Black Soldier Fly Larvae as an Alternative Fish Feed on Growth Performance and Productivity of African Catfish” is original and has been carried out by myself under the supervision of Dr. Mulugeta Wakjira and Dr. Tokuma Negisho. To the best of my knowledge, I confirm that this work has not been submitted for any other degree or qualification at any other university. All sources used in this research have been acknowledged and referenced appropriately. I also declare that any data, figures, or images included in this research are original or have been appropriately attributed to the original source.

Mekash Yirga Beshir

Sign-----

Date-----

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## **Acronym**

ADGW - Average daily gain of weight

ADGL - Average daily gain of length

BSF - Black soldier fly

BSFL - Black soldier fly larvae

CP - Crude protein

FCR - Feed conversion ratio

SGR - Specific growth rate

## Abstract

Catfish (*Clarias gariepinus*) is one of the best candidate aquaculture species. Feed is crucial in fish culture, especially in the early stages. Aquaculture production in Africa is marginal mainly due to inefficiencies in the production systems ascribed to a lack of high-quality fish feed, particularly in sub-Saharan countries like Ethiopia. The major fish feed protein ingredient in fish farming in Ethiopia especially in south west Ethiopia is (BM) that is often times consumes for preparation and results in risk of disease. 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, survival and proximate compositions of the African catfish (*Clarias gariepinus*) reared on diets containing BSFL meal in a formulated fish diet at different rates of substitution. Treatment diets were formulated for BSFL meal to substitute formulated basal diet at the rates of 0% (C), 25% (D1), 50% (D2), and 75% (D3). All diets were formulated to meet the nutritional requirements of catfish. The catfish were stocked in eight tanks each measuring 2 by 0.5 meters and each tank held eight pieces of catfish. The experiment was conducted in a completely randomized design with each treatment in duplicates. The performance of the African catfish was determined by recording the weights, lengths and mortality biweekly for two months. Analysis of variance was carried to determine the effects of the treatment diets on the weight gain and carcasses characteristics. Water quality parameters including dissolved oxygen, temperature, 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 0.54g/day and 0.51g/day respectively. However, the growth rates of the African catfish fed on diets with 0% and 25 % BSFL meal were not significantly different ( $P>0.05$ ). 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. Analysis of the carcasses showed that an increase in BSFL meal led to an increase in the crude fat content of the carcasses. The inclusion of BSFL meal did not negatively affect the nutritive composition and carcass quality of the African catfish. Substitution of BSFL meal for formulated basal diet 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.

**Key words:** Aquaculture, Black soldier fly, *Clarias gariepinus*, Fish feed, Growth performance

# 1. Introduction

## 1.1 Background of the Study

Aquaculture is among the fastest-growing food production systems globally, producing nearly half (47%) of the total world fish production (FAO, 2018) which depends heavily on aqua feed input. It has become responsible for the continuing impressive growth in the supply of fish in contrast to the relatively static growth of capture fishery. The rapid growth of the aquaculture sector results from the progressive intensification of using quality aqua feeds and production systems (FAO, 2006). However, aqua feed is the major determinant factor that accounts for up to 70% of the total aquaculture production costs in semi-intensive and intensive types of systems (El-Sayed, 2004; Dorothy et al., 2018). As a predominant source of protein, fish meal is a highly preferred ingredient for formulating aquafeeds though feed production depends on many protein and energy ingredient sources (El-Saidy and Gaber, 2003; Hasan et al., 2012).

Fish meal is an excellent protein source in aquafeeds because of its high digestibility and palatability, high protein content, balanced amino acid, rich in omega-3 fatty acids and having physical properties that improve the preparation of nutritious feeds (Kirimi et al., 2016). However, the increase in the cost of fish meal poses real problems for cost-effective feed formulation (El-Saidy and Gaber, 2003; El-Sayed, 2004), and its supply is subjected to overfishing and not readily available. Nowadays, there is a growing concern for reducing the inclusion rate of fish meal in aquafeeds and searching other economically viable, abundant, and environmentally friendly options for replacement of fish meal and fish oil.

Commercially formulated diets lack the extent of accessibility and acceptability by fish farmers to adopt sustainable commercial fish production (El-Sayed, 2004; Jackson, 2012). Formulated feeds used in intensive aquaculture are among the most expensive fish feeds available because of the high cost of the protein source materials needed to prepare aquafeed. Nonetheless, suitable dry feeds should be easily accessible and match the dietary requirements of the species when it comes to rearing larvae and fry. A foundational species in aquaculture views dietary protein as crucial since it has a substantial impact on growth, fish survival, and feed costs (Giri et al., 2003). The utilization of dietary protein for growth depends on the quantity as well as quality of feed proteins.

Different locally available feed stuffs for fish feed have been identified, and their proximate nutrient composition has been analyzed (Assamnew *et al.*, 2012). However, these feed stuffs have not been formulated into commercial or local fish feeds. Agriculture in Ethiopia being the main source of economy, can be a cheap source of locally available fish feed ingredients. However, no research has been conducted to formulate feed for different stages of *C. gariepinus*

from locally available materials so far. For the aquaculture sector to develop in Ethiopia, feed from locally available ingredients has to be produced to available quality fish fry.

Protein components of animal origins like poultry by-products and their combinations, meat and bone meal, feather meal and blood meal, fish-offal, agroindustrial by-products and other local fishery by-products are among the reasonable alternatives in order to satisfy the enormous demand for protein-based aquafeed (Mondal *et al.*, 2012; Zenebe Tadesse *et al.*, 2012). But, there are adverse health hazards with using animal by-products due to disease outbreaks like bird flu, swine fever virus, and mad cow diseases (Wang *et al.*, 2008). Besides that, the non-conventional feedstuffs of animal origin are unavailable in large commercial quantities to sustain the aquaculture industry. Conversely, plant proteins are not only less risky, but they are also abundant offering a more suitable option as alternative protein sources in fish feeds (Naylor *et al.*, 2009; Alayu Yalew *et al.*, 2019) although they often contain antinutritional factors (ANFs), which can affect growth performance and fish health. Therefore, it is justifiable to investigate insect based proteins to augment current fish feeds.

There is a lot of promise for employing insects as fish food because fish naturally consume insects (Rumpold and Schlüter, 2013). Most insect and larval stages have a balanced amino acid composition and are rich in lipids, minerals, and vitamins (Henry *et al.*, 2015). Moreover, it is possible to produce insects from the majority of organic waste streams, which can transform the waste into a high-quality feedstock while reducing its inherent contamination potential (Barroso *et al.*, 2014). In addition, raising insect's results in fewer greenhouse gas emissions than raising animals (Oonincx *et al.*, 2010). The ability of *Hermetia illucens*, one of the promising insect species examined thus far, to convert a variety of organic wastes into high-quality nutrients (protein > 40% and lipid > 30%) for animal feed, as well as its omnivorous lifestyle, have led to its selection as a promising candidate for sustainable mass production (Henry *et al.*, 2015).

The BSF has been suggested as a tool for decreasing organic waste and increasing the synthesis of crude protein and fat (Newton *et al.*, 2005). When given animal manure or plant matter, black soldier fly larvae (BSFL) can transform low-value organic waste into protein-rich biomass (Diener *et al.*, 2009). The dry body of BSFL includes 42%-44% crude protein and 31%-35% crude fat after conversion from fish offal or livestock manure (Yu *et al.*, 2009), making it an acceptable source of food for animals (Bondari and Sheppard, 1981). Fish fed with BSFL instead of FM had no harmful effects, according to some researchers (Sealey *et al.*, 2011). Another interesting aspect about BSFL is their antibacterial activity (Elhag *et al.*, 2017), which may increase the immunity and growth similarly to dietary antibiotics in low, sub-therapeutic doses (Gadde *et al.*, 2017).

Currently, Black Soldier Fly rearing is done at a small scale in east African countries like Kenya, Uganda, and Tanzania (Edea *et al.*, 2022). However, their potential suitability as aquafeeds is not well studied and reported particularly in Ethiopia. In the country there is limited information available on the existence, status, abundance, and distribution of BSF to use as a potential alternative sustainable protein-rich ingredient for poultry and fish feeds. Utilization of these resources to fulfill the natural resource base promises a considerable potential for success and, thus it is imperative to address the problems related to locally available feed formulation, in minimizing production cost and finally make an attractive aquaculture production system to farmers in Ethiopia. Therefore, the objective of the present study was to evaluate effectiveness of Black Soldier Fly-based fish feeds, produced from locally available biowastes, on the growth performance and Productivity of African catfish (*Clarias gariepinus*)

## **1.2 Statement of the Problem**

A large amount of land and other natural resources in Africa offer great opportunities for the development of aquaculture (Brummett *et al.*, 2008). Nevertheless, aquaculture production in Africa is marginal, mainly due to inefficiencies in the production systems ascribed to a lack of high-quality fish feed (Lazard *et al.*, 2010). Aquaculture was introduced to Ethiopia in 1974 by the establishment of Sebeta Fish Breeding Center (now the National Fisheries and Other Aquatic Life Research Center) by the help of the Japanese Overseas cooperation (JICA) (Rothuis, *et al.*, 2012). But As in most African countries, aquaculture in Ethiopia is underdeveloped. Expectations were not met by the sector's development. There haven't yet been any established commercial farms. Small-scale aquaculture operations are conducted in modest rural fish ponds with a surface area of  $100m^2$  to  $300m^2$ (Rothuis *et al.*, 2012). The underdevelopment of the sector in the nation is a major contributing factor in many of the issues. The lack of quality and sufficient supplies of seed and feed are the most significant problems facing Ethiopian aquaculture.

The use of traditional feeds such as fish meal and soybean as sources of protein in fish feed is at stake due to the associated economic, environmental, and production problems. The use of the black soldier fly (BSF), *Hermetia illucens*, as a bioreactor to convert local biowaste into nutritionally improved fish feeds and other useful products represents a potential option. This bioconversion of wastes into aquafeed represents a viable and sustainable solution to the challenges of fish feed in order to promote aquaculture development and address environmental issues. The BSF-based aquafeed also has the benefit of improving fish health via its antibiotic nature.

Despite the fact that many research projects have been conducted on BSF, the effectiveness of the BSF larval biomass produced from various substrates in relation to local fish feed in promoting fish growth has not been thoroughly investigated in Ethiopia. Moreover, past projects were limited in the scope of their geographic coverage as well as the biowaste used to achieve their goals. Therefore, this research project aimed to evaluate effectiveness of Black Soldier Fly-based fish feeds, produced from locally available biowastes, on the growth performance and Productivity of African catfish.

### **1.3 Research question**

- How does the inclusion of Black soldier fly larvae in practical diets affect the overall productivity and growth performance of African catfish (*clarias gariepinus*) compared to conventional fish feed ingredients?
- What is the impact of black soldier fly larvae-based diets on the nutritional composition particularly the protein and fat content of African catfish carcasses compared to traditional fish feed ingredients?

### **1.4 Objectives**

#### **1.4.1 General objective**

- To evaluate effectiveness of Black soldier fly larvae fish feeds, produced from locally available biowastes, on the growth performance and Productivity of African catfish (*Clarias gariepinus*) for sustainable aquaculture development in Ethiopia

#### **1.4.2 Specific objectives**

- To evaluate the effects of replacement of dried diet in the formulated conventional fish feed ingredients on growth performance, well-being, survival rate, productivity of African catfish Juveniles.
- To evaluate the effect of replacement of BSFL diet in the formulated conventional fish feed ingredients on nutritional composition of African catfish carcass

### **1.5 Significance of the Study**

This study improves fish feed problem especially in small scale aquaculture. BSFLs are good source of well-balanced nutrient for effective growth of fish than locally available feed stuffs do. This increases fish productivity and making fish cheaper and more affordable to more people. It also an alternative protein sources of good nutritional qualities that are ideally readily available and more cost-effective than commercial fish feed. These reduce production costs and create a good-quality product suitable for any small- or large-scale production system. Therefore, this study proves that BSF larvae could potentially increase the performance of fish more than commercial fish foods do. The promotion of the farming of BSFL as a source of proteins for

animal feeds, including fish a feed that aims at making fish cheaper and more affordable to more people is a direct contribution to the pillar of food security. In addition, the promotion of the utilization of BSFL biomass instead of farmed crops such as soybeans ensures less utilization of land, water, and a reduction in the use of aquatic fishmeal in fish feeds, which will lead to the conservation of the biodiversity of this overexploited resource (Tacon and Metian, 2008). This contributes to the conservation of aquatic biodiversity and also conservation of limited resources such as land and water (Merino *et al.*, 2012). The study's contributions to sustainable farming of the black soldier fly can contribute to lessening dependency on African catfish juveniles.

## **2. Review of Related Literature**

### **2.1 The role of aquaculture in food security and nutrition**

Food security is the situation where all the people existing, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life, as claimed by the definition of Food and Agriculture Organization (FAO) (Schmidhuber and Tubiello, 2007). Aquaculture in small farmer system in rural areas provides a high quality of animal protein and essential nutrients, especially for nutrition vulnerable groups, such as pregnant and lactating women, infants, and pre-school children. In fact, almost half of the child deaths around the globe are linked to malnutrition. In numerical reading, it is around 3 million young lives every single year (“UNICEF STATISTICS 14”, 2015). It was proven that after supplied with sufficient needed nutrition which can be found in fishes, such as vitamin B12, calcium, and potassium, unfortunate cases like child blindness and infant mortality has substantively decreased (Ahmed and Garnett, 2011). In rural aquaculture context, most of the time farmers’ household tend to eat the small fish which fails to meet the market size and left the bigger one which can fetch higher prices (Ahmed and Garnett, 2011). Occasionally, some rural communities do practice by giving out fishes as a type of payment to laborer’s working in the farms (Irz *et al.*, 2007). These small fishes are eaten together with their head and bones, added more micronutrients, vitamins and mineral that could not be found in larger fish (Ahmed and Garnett, 2011). Indirectly, the practice of collecting ‘free fish’ from fishponds has contributed as the main nutrient source to the poor families in rural areas, and helped in reducing malnutrition among young children.

The contributions of aquaculture to food security to the public health enhancement were clearly illustrated in Pacific Island Countries and Territories through diversification of tuna farming. Apart from the economic gains, the tuna resources are impressive in a way that they assisted in resisting the high and rising prevalence of non-communicable disease of the regional people over the region (Bell *et al.*, 2015). Non-communicable disease such as heart disease and obesity could happen among the poor. This was due to their high dependency on imported and processed foods as their net food production per capita which often severely destroyed by extreme natural climate disaster (Bell *et al.*, 2009). In the midst of raising nutrition and health implication, tuna farming managed to provide stable food supply and fulfil food security of the poor in all three outmost dimensions: stabilized food availability, provided the villagers sufficient access to it and ability to utilize it. Locally-canned tuna turned out as an affordable high quality and non-perishable food source for the remote inland residents, helping them to achieve self-sufficiency without dependent on imported goods which are subjected to fuel prices fluctuations that added more

pressure to the low economic status group population (Pilling *et al.*, 2015). Additionally, aquaculture by rural communities helps in increasing the availability of fish in both local rural and urban markets. According to the law of supply and demand in economics, when the supply of an item increase, automatically the price for the item will go down, provided there are no external constraints (Gale, 1955).

The fisheries and aquaculture sectors in Africa are increasingly contributing to food and nutrition security, foreign exchange, employment, and livelihood support services (De Graaf *et al.*, 2015). Aquaculture in Africa is still in its infancy and is practiced in only a few countries fetching an estimated 3billion American dollar annually (De Graaf *et al.*, 2015). Although the aquaculture industry in the continent is growing faster than any other part of the world, Africa contributes least to the amount of fish produced, consumed, and traded globally (UN, 2017). For instance, aquaculture contributed 17% of total fish production in Africa, which is equivalent to a paltry 2.5% of global fish production in 2016 (FAO, 2012). Taken against the backdrop of wider regional food insecurity and a projection that Africa's population will double by 2050 (Hounmanou *et al.*, 2018). Aquaculture is poised to play an important role in providing valuable animal protein foods to poor and food-insecure populations (Kobayashi *et al.*, 2015). Considering that 33% of the wild fish stocks are overexploited, aquaculture will play a critical role in meeting increased fish demand in Africa (Chan *et al.*, 2019).

Ethiopia is the richest country with natural and man-made water bodies. It is home to 14 major rivers, 25 major lakes and 14 major reservoirs (Gashaw Tesfaye, 2014). Despite the presence of these aquatic resources, food security is still the major problem in the country (WFP, 2020). Studies show that about 25% of the population which is equivalent to around 25 million people have food security problem, 31 percent of the population are undernourished that is getting < 2,550 Kcals per adult equivalent per day (WFP 2020). Small-scale fisheries and aquaculture have been recognized as important opportunities for enhancing household food security.

The contribution of aquaculture to food and nutrition security is not only just an issue of where aquaculture occurs but also of what is being produced and how and whether the produce is as accessible as that from capture fisheries. The range of fish species produced by an increasingly globalized aquaculture industry differs from that derived from capture fisheries. Farmed fishes are also different in terms of their nutrient content, a result of the species being grown and of rearing methods. Farmed fish price affects access by poor consumers while the size at which fish is harvested influences both access and use (Beveridge *et al.*, 2013).

The contributions of fisheries and aquaculture can be entertained by direct and indirect mechanisms. The direct mechanism is the contribution for the direct consumptions from the

production. For instance, poor people in developing countries tend to depend essentially on carbohydrate-based diets for their nutritional intake. These are, however, relatively low in protein and micronutrients. In this context, fish can play a particularly important role in combating micronutrient deficiencies, as they contain high quality protein, essential fatty acids and also key micronutrients such as vitamin A, iron, calcium, zinc and iodine (Kawarazuka and B'en'e, 2011). It is as a source of essential fatty acids and micronutrients, superior in both qualitative and quantitative terms to other animal-source foods, that may be of greatest importance in food and nutrition security terms. On the other hand, studies published in the literature report an increase in household consumption of fish for those who invest in pond-based aquaculture or in integrated agriculture-aquaculture. Consuming fish produced by their own ponds is a way for households to directly improve nutritional status through aquaculture (Kawarazuka, 2010).

## **2.2 Lack of nutritious feed as a bottle neck for aquaculture development**

Past global strategies to solve food problems have mainly aimed at increasing agricultural production at both the household and national levels and ensuring safe storage of harvests (Brown and Kane, 1995). These strategies have however, not been successful in the third world, mostly because of declining land sizes, stagnant farming technology, poor infrastructure and an ever-expanding population. As a result, fishing is touted as the only sector with the potential to cope with the demands of the rising population (Kassahun *et al.*, 2012).

Much of the fish currently consumed in Africa mostly comes from the natural rivers and lakes in the continent. However, there is concern that the capture fisheries have reached their natural limits and improvements of food security through fish consumption now rely on aquaculture (FAO, 2010). The paradox is however that aquaculture uses wild caught fish for fishmeal production and therefore diverts a food source that could be consumed by humans. Given that about 30% of wild fish catches are used to produce fishmeal for farmed fish feeds, the continued future availability of fish meal is not sustainable (Tiu, 2012).

The growing demand of fish for fishmeal as well as for domestic consumption has led to its severe reduction. The situation has negatively impacted food security and the livelihoods as importation makes the product expensive and unaffordable (Nyandat, 2007). The exorbitant cost of fish feed now accounts for over 60% of the total production cost (Abarike *et al.*, 2013). This has made aquaculture an expensive venture and therefore hindered the potential of the sector to bridge the gap between fish demand and supply (Gabriel *et al.*, 2007). There is therefore need for an alternative protein source, preferably produced on by-products and materials which are not suitable for direct human consumption and local production of fish feed from inexpensive

and locally available feedstuffs to reduce the cost of production, provide a cheaper means of meeting the protein requirements, improve food security and reduce the level of poverty in developing countries (Hoffman *et al.*, 2000; Gabriel *et al.*, 2007; Kassahun *et al.*, 2012).

Ethiopia, agriculture has important share in gross domestic product and agricultural by-products can be a source of feed and fertilizer for small-scale farming and increases the natural production of the ponds (Demese Chanyalew *et al.*, 2010). Fish obtain the energy they need by eating protein, lipid and carbohydrate are known as macronutrients and small amounts of minerals and vitamins are essential called micronutrients (Carmen and Geoff, 2007). Hence, two or more ingredients should be mixed into homemade, laboratory and commercial feed formulations. Supplementary feeds in fish culture may consist of by-products such as plant by product and animal processing by product. For the commercial fish farming, such by-products can reduce feed costs by replacing some formulated feeds. But, how to process such by products at homemade, laboratory and commercial feed for small scale farming is not started yet in Ethiopia and presence of non-starch polysaccharide (NSP) and high fiber content, imbalance amino acid profile, and associated limitation (i.e. anti-nutritional substances) in plant by product protein. (Francis *et al.*, 2001; Sinha *et al.*, 2011). Therefore these can be used as production substrates for currently underutilized animal protein sources such as farmable edible insects for inclusion in the compounded feeds (Van Itterbeeck *et al.*, 2014). The transformation of these locally available by-products low in protein into high quality fish protein can be a major contribution to improving the protein supply for the local human population.

Global enthusiasm for insect farming is growing as its diverse range of potential commercial and environmental benefits become well recognized (Devic, 2016). Insects which can be produced on organic waste products provide a more sustainable source of protein for animal feed. Use of farmable edible insects as feed ingredients is associated with certain advantages: they are rich in proteins, fat, energy, vitamins and minerals; have higher feed conversion efficiency compared to livestock and therefore use less feed; less land than crop production; have great acceptance from poultry and fish as part of their natural diet and are mostly omnivorous and therefore grow on different substrates (van Huis *et al.*, 2013).

However despite the tremendous potential to be used as a feed item of many livestock animals, they are currently not widely used perhaps due to inadequate knowledge about their potential (Devic, 2016).

### **2.2.1 Protein demand against supply**

A swift raise in population growth and urbanization have raised alarm on two key concerns specifically food security namely the supply of proteins, and management of wastes produced

from increased consumption (FAO, 2011; The Economist, 2014; Alooh, 2012). Urbanization and expansion have led to an inclination to foodstuff rich in animal products and intensified waste production. Therefore, the need for animal protein demand for animal proteins such as meat and milk is predicted to rise by 58% and 70% in turn in 2025 in relation to the levels in 2010 (FAO,2011).

More time and land have been put into raising the amount of conventional cattle, poultry and expanding the aquaculture sector in order to satisfy the anticipated growth in demand. Through resource overuse and environmental deterioration, these activities have a detrimental impact on the environment (Foley *et al.*, 2011; Mekonnen and Hoekstra, 2012). At all levels, from local to global, animal agriculture significantly contributes to serious environmental issues including pollution (Steinfeld *et al.*, 2006). Furthermore, aquaculture diverts a food supply that could be utilized by humans by using wild caught fish for fishmeal manufacture. As a result of the increased competition from human consumption, the ongoing availability of fish meal in the future is not sustainable; thus, other protein sources for animal feeds, poultry, and aquaculture are required (FAO, 2012).

### **2.3 Insect protein demand**

The demand for insect proteins differs by area. The human food sector is driving demand in Asia and South America. This is particularly prevalent in nations where crickets and mealworms are grown and consumed, such as Thailand, Lao People's Republic, and Mexico (Hanboonsong *et al.*, 2013). Several firms have provided tiny amounts of insect meals to aquafeed makers to date (Alfiko *et al.*, 2022). A growing number of investors are investing in various start-up companies that generate insect meals (Rumbos *et al.*, 2019). Insects initially appeared in aquafeeds less than 40 years ago, although tremendous advances in culture, optimizing production, nutritional benefits, and feeding trials have been documented (Daniel, 2018) Insect meal production is expanding quickly in China, Europe, North America, Austria, and Southern Asian countries (Alfiko *et al.*, 2022). The demand for insect protein, mainly as an ingredient in feed and pet food is predicted to reach 500,000 metric tons by 2030, up from the current market of around 10, 000 metric tons globally (Bryne, 2022). In industrial automated mass scale production most often produces at least 1 ton a day of dry insect weight (Smith and Barnes, 2015). Currently only a few thousand metric tons of insect proteins are used in aquafeed (Bryne, 2021). In Africa, the poultry and fish industries are the primary consumers of insect protein (Schönfeldt and Hall, 2012); Leek, 2017). ICIPE in Kenya, and Chinhoyi University of Technology in Zimbabwe are able to mass produce black soldier flies and GREEiNSECT n Kenya, a producer of crickets is among a few notable producers in Africa. Despite the region's enormous potential in terms of

climatic conditions and agricultural waste supply as raw materials, industry is still in its infancy. Strict legislation in Europe and North America has limited the usage of insects to the aqua feed and pet food markets, with potential prospects for the livestock and poultry sectors (Leek, 2017).

## **2.4 Biology of Black soldier fly**

The Dipteran order of insects, which includes mosquitoes, black soldier flies, midges, fruit flies, and house flies, is known as the 'real flies' or 'two-winged flies' (Resh and Carde, 2003). The fly to be discussed further from this order is *H. illucens* (BSF).

### **2.4.1 The Black Soldier Fly (*Hermetia illucens*, L, 1758) Diptera: Stratiomyidae.**

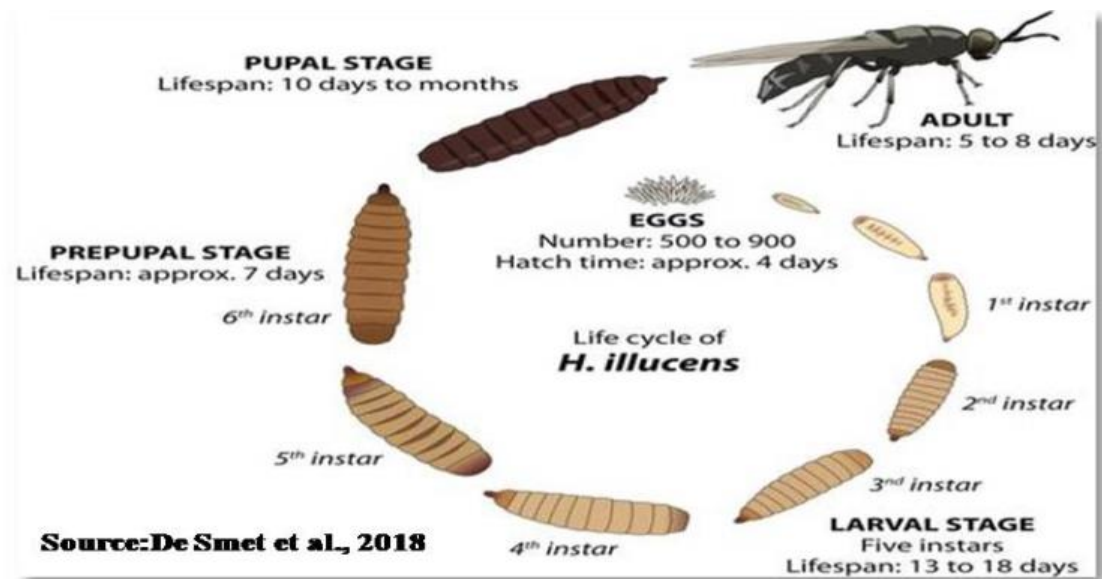
Black soldier fly (*Hermetia illucens*) insects belong to the Order Diptera and Family Stratiomyidae (Liu *et al.*, 2017). Its development is primarily a four stage cycle: egg, larvae, pupae and adult fly (Li *et al.*, 2011a). The egg of a black soldier fly develops to larvae, which is the 6th stage, prior to pupation and finally develops to a mature insect (Alvarez, 2012).

Black Soldier 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). The larvae can be processed as feeds for cows, swine, and various poultry species and also for aquaculture species (Wang and Shelomi, 2017). Some crude fats of BSF larvae can be changed to biofuels (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). Currently black soldier fly larvae oils are been tested for use as skin care products in the multibillion beauty industry (Sangduan, 2018). It is easy to mass produce BSF larvae for use as animal feed, thereby enhancing bioconversion as a commercial venture (Bava *et al.* 2019).

The larvae have been used to degrade the various organic wastes (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 and pig waste (Sheppard *et al.*, 1994). Additionally, Diener *et al.* (2009) revealed that 66-70 % of the total weight domestic wastes were diminished by BSF larvae. The reduction in weight of between 25-55 % of total fecal wastes when BSF larvae were used to control fresh human feces (Banks *et al.*, 2014). 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.

## 2.4.2 Life cycle of the Black Soldier Fly

The BSF goes through the entire life cycle (Figure 1). Larvae mature into pre-pupa in about two weeks under the correct conditions of food, relative humidity, and temperature. Given the correct conditions, pre-pupa take two weeks to mature into pupa in a process known as pupation, which is characterized by the development of an embryo within the puparium (casing), stiffness of the body, followed by immobility. When pre-pupae locate a dry medium to burrow in, they develop into pupae. Pupae in the dry medium go into a sleeping phase for at least two weeks, during which time the embryo develops within their exoskeletal casing. When fully formed, the casing breaks away at the tip, allowing an adult fly to emerge (Sheppard *et al.*, 2002).



**Figure 1: BSF life cycle (*H.illucens*)**

Source: Outlined by Jeyaprakashsabari and Aanand, (2021).

When compared to one day old adults, newly emerging adult flies have underdeveloped, folded wings that progressively unfurl over two to three hours. They also have slightly larger, softer, and greenish colored bodies. Adults live for 5-12 days and mate and lay eggs throughout that period (Diclaro and Kaufman, 2009). A Black Soldier's Lifecycle under ideal conditions, the lifespan of a fly from egg to adult is projected to be 40-43 days however, given poor raising conditions, the time might last up to six months (Popa and Green, 2012). The larval and pupal stages last the longest in the lifecycle (Popa and Green, 2012). Furthermore, the larval stage dictates and regulates the lifetime of subsequent phases as well as the adult stage's productivity (Holmes *et al.*, 2012). It is the most important stage for humans in terms of economic relevance (Mutafela, 2015).

### 2.4.3 The nutrition composition of black soldier fly larvae

Black soldier fly larvae used as ingredients in livestock and fish diets have a good amino acid balance and high crude protein content (Table 1). Biomass quality: crude protein, crude fat and ash of the larvae varied but stabilized at mature larvae and pupae stages (Liu *et al.*, 2017).

**Table 1: The nutrition composition of black soldier fly larvae meal reared on cattle and pig refuse (Haasbroek, 2016)**

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

There are insufficient studies on the total amino acid requirements of African catfish and their requirements standards have been based on those of the channel catfish (*Ictalurus punctatus*) which have been studied comprehensively (NRC, 2011). 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 (Barragan-Fonseca *et al.*, 2017). Such studies have advocated for its use as an alternative feed ingredient in rearing different food animals (Meneguz *et al.*, 2018). 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 (Makkar *et al.*, 2014).

When compared to one day old adults, newly emerging adult flies have underdeveloped, folded wings that progressively unfurl over two to three hours. They also have slightly larger, softer, and greenish colored bodies. Adults live for 5-12 days and mate and lay eggs throughout that period (Diciaro and Kaufman, 2009). A Black Soldier's Lifecycle under ideal conditions, the lifespan of a fly from egg to adult is projected to be 40-43 days however, given poor raising conditions, the time might last up to six months (Popa and Green, 2012). The larval and pupal stages last the longest in the lifecycle (Popa and Green, 2012). Furthermore, the larval stage

dictates and regulates the lifetime of subsequent phases as well as the adult stage's productivity (Holmes *et al.*, 2012). It is the most important stage for humans in terms of economic relevance (Mutafela, 2015).

#### 2.4.4 Ecological requirements for the Black Soldier Fly

BSF requirements differ depending on the stage of development, thus in order to accomplish successful breeding in confinement, the conditions must be monitored and maintained to ensure that they meet the requirements. Temperature, relative humidity, light, nutrition, and pupation substrate are all elements to consider.

**Table 2. Ecological requirements of the black soldier fly at different stages of life**

Stage	Duration (days)	Temperature (°c)	RH (%)	Light intensity
Eggs	4	Above 26	Above 60	-
Larvae 4 days	0-4	26-29	65-75	Photophobic
Larvae 4 days over	4-14	26-35	65-75	Photophobic
Pre-pupa/pupa	10-14	25-30	Low	Photophobic
Adults	5-8	27-30	30-90	Photophilic. Mating occurs between 60- 200 $\mu$ mol/m <sup>2</sup> /s and wavelength of 450nm-700nm

RH (Relative humidity).

Source: Mutafela (2015).

#### 2.4.5 Organic waste as production substrates for BSF larvae

The growth substrate has a considerable influence on major BSFL growth characteristics including as development time, feed conversion efficiency, mortality, pupal weight, and nutritional content (Zheng *et al.*, 2012). As a result, commercial scale use of the technology is required, which will necessitate the use of substrates capable of producing quality larvae in a short period of time while reducing losses due to death. Unfortunately, while it is well accepted that the larvae consume a wide variety of organics, the complete spectrum of substrates for growing BSFL, particularly for biomass production on a commercial scale, remains largely unknown (Leek, 2017).

Organic waste materials are also highly diverse in nature, with fluctuating moisture and nutrient content, making universal applications of findings nearly impossible. (Holmes *et al.*, 2012).

Livestock manures from big, confined animal feeding operations are among them, as are palm kernel waste, pig liver, kitchen waste, rendered fish, and human feces. Hem *et al.*, 2008; Diener *et al.*, 2011; Popa and Greene, 2012; Lalender *et al.*, 2013; Kalová and Borkovcová, 2013;

Nguyen *et al.*, 2013; Zhou *et al.*, 2013; Bankss *et al.*, 2014; Nguyen *et al.*, 2015). Despite the fact that the larvae were able to convert the waste into a more desirable, nutritious, and less hazardous biomass rich in protein (44.4% DM), lipids (23% DM), ash (11- 28% DM), and other valuable elements such as calcium (5-8% DM) and phosphorous (Newton *et al.*, 2005, St-Hilaire *et al.*, 2007, van Huis *et al.*, 2013 ), the objective was to produce biomass for animal feed rather than waste management. However, the composition of BSFL biomass compares substantially to that of fishmeal and soya, which together presently supply more than 90% of the protein required by animal diets (Yu *et al.*, 2009).

The European Food and Safety Authority (EFSA) has approved the use of fruit and vegetable substrates as having the highest potential for use as feed for insect production due to the low risk of transmitting zoonotic diseases to humans when compared to substrates such as manure, catering waste, or prior foodstuffs containing meat and fish, which are not allowed because insects are considered 'farmed animals' (European scientific committee, 2015). Fruits and vegetables have a significant proportion of post-harvest wastage and losses, as well as various byproducts of the fruit and vegetable processing industries, and hence serve as a viable insect-rearing substrate. (FAO 2011, Kalová and Borkovcová, 2013, Nguyen *et al.* 2015, Parra Paz *et al.*, 2015). Furthermore, enormous amounts of fruits and byproducts accumulate at production farms during peak seasons, posing disposal and public health concerns, despite the fact that the only cost to consider for these substrates is collection, transportation, and some moderate processing, such as cutting into small pieces and removing inorganic materials. (Nguyen *et al.*, 2009; Fila *et al.*, 2013). To be considered a protein source in a feeding diet, an appropriate rearing substrate should contain at least 20% crude protein content (Ramos-Elorduy *et al.*, 2002; Munguti *et al.*, 2006; Kassahun, 2012). Food remnants (20%) and a mixture of vegetable and fruit wastes (20%) meet this requirement among all substrates (Munguti *et al.*, 2006; Nguyen *et al.*, 2015). Kalova and Borkovcova (2013) BSF larvae were fed over a 14-day period, 14 different waste types were tested, and only four of the wastes produced adult flies, including post-consumer food waste, indicating that these diets were most suited to larval growth. These findings are consistent with Barry (2004).

#### **2.4.6 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*) (Borgogno *et al.*, 2017). These studies reported that BSF larvae meals can replace fishmeal-based diets. 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 (Stamer *et al.*, 2014). 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 (Sanches, 2016).

Inclusion of BSF larvae meal did not adversely affect the growth, biological and carcass quality parameters of Jian carp (*Cyprinus carpio* var. Jian) (Zhou *et al.*, 2018). 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.

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) (Xiao *et al.*, 2018). 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 immune-competence of the catfish. It is therefore reasonable to evaluate the use of BSF larvae meal in the African Cat fish. 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 (Rimoldi *et al.*, 2019).

## **2.5 The African catfish and Ethiopian Aquaculture**

Ethiopia has high potential both in terms of soil/water and climate with a rich biologic diversity of native fish species to develop a fish culture (Shibru Tedla, 2016). FAO (2014) reported that cold water species farming on the high central plateau over 2,500 m can be achieved throughout the year at approximately 11 % of Ethiopia's surface area. Likewise, the surrounding and central mountains have also favorable temperatures for warm water fish (Aschalew Lakew *et al.*, 2016; Gadisa Natea *et al.*, 2017). In addition, tilapia and other warm water species could also be grown in the lowlands that represent around 33 % of the total area. Furthermore, Eshete Dejen and Zemenu Mintesnot (2012) reported that approximately 1.4%, 55.49%, and 43.1% of the country were found to be highly, moderately and marginally suitable, respectively for commercial Nile tilapia production under a pond cultivation system.

Ethiopia is further endowed with a mean annual flow (runoff) of 122 billion cubic meters with an estimated total length of 80,065 km, comprising 12 drainage basins (8 river basin, one lake basin and three dry water basins). The country also has many lakes, small water bodies and floodplain areas of around 13,637 km<sup>2</sup> (Gashaw Tesfaye and Wolff, 2014). The reservoirs which are under construction such as Gilgel-Gibe III and the Grand Ethiopian Renaissance Dam

(GERD) are expected to increase the total inland water by over 15% when completed and goes operational (Aschalew Lakew *et al.*, 2016; Tola Meko *et al.*, 2017).

Fish consumption in Ethiopia is generally very low (0.5 Kg/person/year) compared with the average per capita consumption reported (9.9 Kg/person/year) in other African countries (FAO, 2020). However, in towns near the lakes and rivers of the Ethiopian Rift Valley and Gambella area, the per capita consumption was reportedly close to the African average. Moreover, in some regions of the Rift Valley there is growing demand for food fish. High demand for food fish is being attributed to growing human population, intensive economic activities and increased family incomes in Addis Ababa and major cities such as Hawassa, Adama, Bahir Dar and Mekelle. In addition, awareness of the health benefits of fish by the urban community could be the driving force for increased fish consumption in the cities (Aschalew Lakew *et al.*, 2016). Fish of commercial importance including the Nile tilapia and African catfish collected from Rift valley lakes were reported to be rich in the long chain of omega-3 polyunsaturated fatty acids like eicosapentaenoic acid and docosahexaenoic acid (Zenebe Tadesse, 1999). It is also well established, that the w3 polyunsaturated fatty acids are medically important for humans in preventing cardiovascular illnesses or lower cholesterol accumulation in blood vessels (Zenebe Tadesse, 2010; Aschalew Lakew *et al.*, 2016).

In Ethiopia, aquaculture operations have been restricted to the introduction of exotic and indigenous freshwater fish into several man-made and natural bodies of water (Kassahun Asaminew, 2012; Aschalew Lakew *et al.*, 2016; Gadisa Natea, 2019). Because of its adaptability to a wide range of environmental conditions and the high demand of the fish by local consumers, the Nile tilapia (*O. niloticus*) has been stocked to many small water bodies (Aschalew Lakew *et al.*, 2016; Gadisa Natea *et al.*, 2017). Despite the fact that Ethiopia has a diverse range of fish species, there is a strong reliance on Nile tilapia. That is, Nile tilapia is the country's benchmark for fish farm production, narrowing Ethiopia's aquaculture production diversity. However, the economic importance of African catfish in the country's fishery products is great alongside Nile tilapia, although their pond farming has not yet well practiced like in other African countries. (Gadisa Natea *et al.*, 2017).

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 (Ponzoni and Nguyen, 2008). This species of fish is found in almost all water bodies including swamps, seasonal pools, seasonal rivers and lakes (Weyl *et al.*, 2016). Its wide distribution is due to its ability to use atmospheric air and tolerance to low dissolved oxygen (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.

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). It 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).

The African Catfish production in sub-Saharan African is mostly a small scale semi intensive venture among rural farmers (Ngugi *et al.*, 2007). It 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.

## **2.6 Sustainable and nutritious feed to promote aquaculture in Ethiopia**

Availability of feed resources is the major factor contributing for the development of small-scale aquaculture in Ethiopia. Commercial fish feeds are not readily available in the country. Even though, Alema Kodijs PLC, one of the feed mills in Ethiopia mainly formulating and producing feeds for poultry and livestock has started producing fish feeds, most of the aquaculture practice depends on farm made feeds in the country (Mulugeta Wakjira *et al.*, 2013). Farm made aqua feeds are cheaper than commercial aqua-feeds and allows fish farmers to use locally available agricultural by-products (Akewake Geremew, 2015). Several studies have indicated the possibility of sustaining Nile tilapia farm using locally available ingredients for the preparation of supplemental and compound feeds (Firew Admasu *et al.*, 2017). The availability of different animal and plant feedstuffs for small scale aquaculture in Ethiopia have been identified (Kassahun Asaminew, 2012). The integration of this feed stuffs in fish feed formulation resulted in enhanced growth performance in the farmed fish.

Commercially produced compound feeds are readily available for aquaculture in developed countries. In most developing countries formulated feeds for fish are scarce or entirely unavailable (FAO, 2005). Although some developing countries are importing formulated fish feeds, these are usually too expensive for an economically viable fish production. Since feed

costs represent 40–50 % of the total variable production costs (Craig and Helfrich, 2002), locally produced and reasonably priced feedstuffs of sufficient nutritional quality are a key element in the development of aquaculture in countries like Ethiopia (Gabriel *et al.*, 2007). The inclusion of locally available feed components will essentially depend on their nutrient content. There are number of potential feed stuffs of different by product available in the country and proximate analysis show that feedstuffs in the categories of agro-industrial by-products, herbaceous forages, cereals and legume grains, fodder trees and shrubs include several potential feed components for developing aqua-feeds for small-scale aquaculture especially for *O. niloticus* in Ethiopia as targeted herein. In contrast, crop residues, roots and tubers and other food crops and less common feeds were found to be probably less important even for low protein diets which are likely to be used in this type of aquaculture (Kassahun *et al.*, 2012).

### 3. The Study Area and Methods

#### 3.1 Description of Study Area

This study was conducted at Department of Biology, in Aquaculture and fisheries management laboratory of Jimma University, located 350 km southwest of Addis Ababa at an altitude of 1700 m above sea level. The mean daily temperature and annual rainfall of the study area is 20.71°C and 123.01 mm, respectively (Jimma Meteorological Station).

#### 3.2 Collection of feed ingredients and processing methods

This study was used two types of feed ingredients, such as locally available fish feed ingredients (Brewery waste (BW), Rumen liquor (RL), poultry manure (PM), Blood meal (BM)) and natural fish feed using larvae of BSF. The selection of local feed ingredients was done on the basis of their local availability in sufficient amounts, cost and need for disposal. Preference was given to those that are byproducts or waste products, whose incorporation in feeds could also enhance good sanitation (Madu *et al.*, 2003). Brewery waste (BW) was obtained from Bedele beer factory, Rumen liquor (RL) and Blood meal (BM) were obtained from Nearby Slaughter House, poultry manure (PM) was obtained from local chicken-rearing areas around Jimma university. The chemical composition of those feed ingredients are taken based on the results of a preliminary experiment conducted by another MSc research project prior to the start of this experiment.



**Figure 2:** Feed ingredients

### **3.3 Mass culturing and harvesting of BSF larvae**

The mass culturing of BSF larvae typically was based on a 50:50 combination of poultry manure and brewery waste at a feeding rate of 100 grams of feed per gram of larvae. The feeding rate of 100gm feed per gram of larvae was selected based on the results of a preliminary experiment conducted by another MSc research project prior to the start of this experiment, indicating that this rate can maximize the growth and development of black soldier fly larvae and maximize the conversion of organic waste into larvae biomass. Once the feedstock was prepared prepupa (one of the life stage of BSFL) were introduced from Addis Abeba University. A suitable breeding habitat was prepared to encourage mating and egg laying for emerging adults.

#### **3.3.1. Establishing BSF Colony**

The BSFL seed was initially obtained from Addis Ababa University insectary research unit. The colony was subsequently established at the Aquaculture and Fisheries management Research site of Jimma University. A suitable breeding cage was established to encourage mating and egg laying for emerging adults. A large cage (a mesh enclosure) which is commonly called love cage (0.80m width x 1.65m height) with sufficient ventilation and sufficient volume was prepared for house the adult BSF inside a mini-greenhouse. The cage was placed at the side of the green house with good sun exposure to trigger mating of the adult fly. In the love cage, adult flies mate and females lay their eggs into eggies or egg deposition substrates.

A mixture of organic matter (fruit and vegetable leftovers, animal waste, maize bran) was stored in a covered container for a few days before placing it inside the cage to make more attractive odors for BSF which acted as attractants. This odorous organic materials with egg traps (corrugated cardboard and wooden sticks) was placed inside the cage, ensuring easy access for the flies to lay their eggs. The egg traps were observed for BSF eggs on a daily basis. White or light yellow egg clusters was collected from egg traps regularly. The eggs from the egg trap scraped on a fine wire mesh and placed 1.5cm above a mixture of substrates (wheat bran) and transferred to the incubator (28°C) and hatched in to larvae within 48 to 72 hours. Once the eggs hatched, the young larvae transferred to the prepared substrate in the larvarium for further rearing until onset of the 5<sup>th</sup> instar of the larvae stage. An equal part of poultry manure and brewery waste was prepared based on the weight of neonates and Placed the prepared substrate mixture in the rearing container to create a suitable feeding area for the larvae. Black soldier fly larvae were introduce and evenly distributed to the substrate mixture at a specified density. After the larvae reached its fifth instar which is dark brown in color and largest size before pre pupation, it was harvested by Negative Phototaxis which means exploit the larvae's aversion to light by placing a light source on one side of the container. The larvae were migrated away from the light,

allowing for easier collection on the opposite side. After harvesting of the larvae in their late instar stage (5<sup>th</sup> instar), the larvae were maintained in the container for a period of 48 hours without any kind of feed given. This duration allows sufficient time for the BSFL to evacuate most of the gut content.

Solar tent dryer was used in drying BSFL samples fed on different substrates. The samples were weighed before drying, then killed with hot water, cleaned with running tap water, and rinsed in distilled water. The cleaned samples were placed on drying trays and placed in the chimney solar dryer under the sun. The larvae were dried for three days. After drying, dried larvae were weighed, grinded and placed in labelled zip-lock bags and stored in a cold, dry (room temperature) location for fish feed preparation.



**Figure 3:** Production of larvae and post-harvest methods of larvae meals

### 3.4 Feed preparation

Predetermined proximate analysis *Hermetia illucens* larvae meal, which was reared on combined locally available bio wastes which is poultry manure and brewery waste (50:50) at a feeding rate of 100g per gm of larva and produced the best biomass, and the other ingredients such as brewery waste (BW), poultry manure (PM), rumen liquor (RL), and Blood meal (BM) were purchased from different sources for the experimental diet formulation for fish. The diets were formulated to partially or wholly replace formulated conventional feed ingredients with BSF larvae meal. The control diet (C) was contained formulated conventional feed ingredients and with no BSF larvae meal. The method of combining selected feed ingredients in varying proportions has to

comply with predetermined nutrient requirements. In this study the nutritional proportions in the control diet (C) formulated from conventional feed ingredients was determined by using Pearson square 2 method and algebraic equations, the most commonly used methods for balancing crude protein levels. The proportion of feedstuffs in control diet were calculated and mixed using Pearson square 2 method and algebraic equations to achieve a desired dietary crude protein level. Then the other three experimental diets were gradually replaced feed ingredients with mashed BSFL at the inclusion rates of 25%, 50% and 75%. The experimental diet were feed daily to the fish at a rate of 5% of their body weight. Frequency of feeding were two times per day for two month for Juveniles. The amounts of the feed was adjust based on the body weight of the fish on sampling day.

The diets were formulated to partially or wholly replace blood meal with BSF larvae meal. The control diet (C) contained blood meal as the protein source and with no BSF larvae meal. For diets D1, D2 and D3 BSF larvae meal was included to replace blood meal at inclusion rates of 25%, 50% and 75%

**Table 3. Percent contributions of each feed ingredient to the fish diets used in the study (the values are in percent).**

<b>Diets</b>	<b>C</b>	<b>Diet1</b>	<b>Diet2</b>	<b>Diet3</b>
Blood meal	20.68	18.69	14.99	9.46
BSFL	0	6.16	14.99	28.37
BW	20.68	25.05	23.35	20.72
PM	29.32	25.05	23.35	20.72
RL	29.32	25.05	23.35	20.72
Total	100	100	100	100
Crude protein (%)	35	35	35	35

C, Control diet (0% BSF larvae meal and 100% blood meal); D1, Diet 1 (25% BSF larvae meal and 75% blood meal); D2, diet 2 (50% BSF larvae meal and 50% blood meal) and D3, diet 3 (75% BSF larvae meal and 25% blood meal).

### **3.5 Source of African catfish juveniles**

Seventy four African cat fish juveniles of uniform sizes were sourced from Boye Lake. Sixty four pieces were used in the experiment in eight tanks. The rest were stored and used for replacement when mortality occurred before the experiment starts. The sample catfish juveniles were acclimatized in the large tank 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 10:00 am and at 4:00 pm. Feed intake was 5% of the total body weight.



**Figure 4:** Juveniles of african catfish

### 3.6 Experimental Design and Procedures

The experimental phase of the research work was conducted in duplicate for where eight tanks with a water volume of 250 liter used. Seventy four juveniles of African catfish were used in the experiment. The experiment was conducted in four treatments each with two replicates each. Treatments were assigned randomly and 8 juveniles were added into each replicate. The study design was a completely randomized design. Prior to the start of the feeding trial the juveniles were acclimatized for one weeks to the environmental conditions and were fed feed prepared from basal diet. Every day the juveniles were hand fed to satiation twice a day at 10:00 h and 16:00 h, at 5% body weight (Munguti *et al.*, 2014). The amount of diet that was provided to each tank of fish was measured and recorded daily. Each diet was fed to two replicate tanks of African catfish and assignment of diets among the tanks was randomly done.

**Table 4.** Dietary composition of catfish feeds and feeding rate used in the study during the two month study period (NRC, 2011; Munguti *et al.*, 2014)

Parameter	Juveniles
Feeding rate	5 %
<b>Crude protein</b>	<b>35 %</b>

The quantity of feed was adjusted after every two weeks throughout the length of the feeding trial based on new weight attained. Data collection was last for eight weeks. The following procedure was used to determine and adjust the amount of feed needed by the fish based on average body weight, (ABW) (Nandlal and Pickering, 2004).

Daily feed ration (DFR) = ABW \* no of fish stocked \* % food requirement

### **3.6.1 Collection of Biological Data**

The mean average weight and length of juveniles in each experimental tank were determined at the beginning of the experiment and every two weeks thereafter. The weights of each of the juveniles were determined by using digital balance. This was done by placing a container on the balance and a tar button was pressed so as to adjust the balance to start from zero. The water level in each tank was first lowered and then the juveniles were caught by using scoop net and they were collected in a container. After that the measurement of the weight of each juveniles were taken one at a time.

The weight measurement was used to determine the specific growth rate, mean daily growth rate, relative growth rate, percentage weight gain, feed conversion ratio and weight gain of the juveniles. The total lengths of the juveniles were also measured according to Lagler (1970) with the aid of a measuring ruler. It was measured as the length of the fish from anterior most extremity to the end of the caudal fin. The total length and weight of the juveniles were taken to the nearest centimeter and gram with the aid of measuring ruler and digital balance, respectively. These measurements were repeated every two weeks for eight weeks. During the period of sampling, the tanks were emptied and cleaned. After weighing, the juveniles were gently returned to the appropriate tanks. The juveniles were not resuming feeding on the day of sampling. Each two week during weighing, the numbers of juveniles in each tank were recorded. A rubber was used to prevent the juveniles from jumping out, intrusion of insects and other foreign bodies. Depleted water was replaced with fresh water to an effective depth of 20cm after each cleaning in order to maintain quality water for the growth of the stocked fingerlings. The health of the stocked juveniles were monitored regularly and dead juveniles, if any, were noted during cleaning and feeding and then were removed carefully from the experimental tanks. Data was recorded and stored in Microsoft Excel at the end of the experiment.

### **3.6.2 Carcass sample analysis**

At the end of the experimental period, four (4) samples from each of treatment were randomly selected and were analyzed in duplicate at the laboratory of animal nutrition, College of Agriculture and Veterinary Medicine, Jimma University according to method of Association of

Official Analytical Chemists AOAC (1995). Fish samples were thawed in the open air in the laboratory. Moisture content of the fish fillets will be determined.

**Moisture content** was determined by the oven drying method following the procedure of the AOAC (1995). Replicates of the minced samples were thoroughly mixed, and known grams of composite fresh fillet were transferred to the dried and weighed dishes. The dishes and their contents were placed in the drying oven and dried for 3 hours at 105 °C in an oven until constant weights was obtained. The moisture content was determined by measuring the weight of a sample before and after the water has been removed by evaporation.

$$MC = \frac{(WWS - WDS) \times 100}{WWS}$$

Where, MC = Moisture content, WWS = Weight of wet sample, WDS = Weight of dried sample After moisture content determined, each of fish species samples were ground into a fine powder using mortar and pestle. Then powdered fillets were kept to polyethylene bags for further proximate analysis. Macronutrient composition; crude protein, crude fat, crude fiber and ash content of the fish fillets were determined.

**Crude protein** in the sample fish fillets was quantified following the procedure of AOAC (1995) by Kjeldahl methods: 0.5 g of powdered fish fillet were weighed into a Kjeldahl digestion flask and then digested by heating at 370 °C for four hours in the presence of 6 ml sulfuric acid, 3.5 ml H<sub>2</sub>O<sub>2</sub>, and 3 g of catalyst Copper Sulfate (CuSO<sub>4</sub>) and Potassium sulfate (K<sub>2</sub>SO<sub>4</sub>). After digestion is complete, the clear solution was cooled for 30 minutes, neutralized by adding 25 ml of NaOH (40%) and diluted using 25 ml of distilled water. Twenty-five ml of distilled water, 25 ml of boric acid, and three drops of methyl blue were added to a receiving 250 ml flask connected to the distiller by a tube. The distillation process was terminated when the volume of the receiving flask reaches between 200 and 250 ml. Note: All reagents were added to the blank except the sample. The nitrogen content was estimated by titration of the borate anion formed with 0.1N HCl. The amount of nitrogen was calculated using the formula:

$$\% N = \frac{N \text{ HCl} \times (\text{Vol HCl TS} - \text{Vol HCl TB}) \times 14 \text{ g} \times 100}{\text{Gram of sample mole}}$$

Where, TS = titrates sample, TB = titrates blank

Crude protein = 6.25 × N

**Crude fat** was determined following the procedure of the AOAC (1995) by the semi-continuous solvent extraction method (the Soxhlet method). Accordingly, for all sample categories, 2 g of dried and ground sample were placed in a porous cellulose extraction thimble, and the thimble was covered with fat-free cotton. The thimble was placed in an extraction chamber, which was suspended above a flask containing the solvent (50 ml of diethyl ether) and below a condenser. The flask, which was dried in a drying oven at 105 °C and contain boiling chips, were placed inside the extraction chamber and heated at 55 °C, and the solvent was evaporate and be moved

up into the condenser, where it was converted into a liquid that trickled into the extraction chamber containing the sample. At the end of the extraction process, which typically lasts for 3 hours, the flask containing the solvent and lipid were removed, the solvent was evaporated in a drying oven at 70 °C, and the mass of lipid remaining was quantified gravimetrically and calculated from the difference in weight of the extraction flask before and after extraction as a percentage. The crude fat in the initial sample was calculated as follows:

$$\text{Fat content} = \frac{\text{Weight of fat} \times 100}{\text{Weight of sample}}$$

**Ash content** was determined by using AOAC method (AOAC, 1985). Briefly, duplicates of 2.50 g of homogenized samples were placed in pre-washed, dried, weighed and marked crucibles, to be ash at 550 °C in Muffle Furnace for eight hours. Then, samples were cooled in desiccator and weighed again. The ash content was calculated as follows:

$$\% \text{ Ash (wet basis)} = \frac{(WAA - TWC) \times 100}{\text{Original sample weight}}$$

Where, WAA = weight after ashing, TWC = tare weight of crucible

Eventually proximate composition in wet base was recalculated from dry base using the formula:

$$\% \text{ Proximate in wet} = \frac{\% \text{ PID} \times (100 - \text{MC})}{100}$$

Where, PID = Proximate in dry, MC = Moisture content

**Crude fiber** was determined as follows

$$\text{Crude fiber} = \frac{A-B}{C} * 100$$

### 3.6.3 Water quality parameters

Throughout the culture period, the water quality in the experimental units was monitored and analyzed to investigate environmental influences on the experiment. Temperature, dissolved oxygen, pH, and conductivity were measured using a paline test. In each of the experimental tanks, two readings were taken for Ammonia determination. Water samples were taken daily at 09:00 and 16:00 hours.

### 3.7 Growth performance and nutrient utilization indices

Weight Gain (WG), Daily Growth Rate (DGR, g/fish/day), Specific Growth Rate (SGR, % weight day<sup>-1</sup>), Food Conversion Ratio (FCR) and Food Conversion Efficiency (FCE, %) were used to calculate all instantaneous growth performance and feed utilizations. The following relationships were used to estimate the above parameters:

1. Weight gain (WG, gm) = Final mean weight (gm) – Initial mean weight (gm)
2. Daily Growth Rate (DGR, g/fish/ day) =  $\frac{\text{Final weight (gm)} - \text{Initial weight (gm)}}{\text{No of culture days}}$
3. Specific growth rate (SGR, %/day) =

$$\frac{\ln \text{ of final weight gm} - \ln \text{ of initial weight gm}}{\text{No of cultured days}} \times 100$$

$$4. \text{ Feed Conversion Ratio (FCR)} = \frac{\text{Total weight of dry feed (kg)}}{\text{Total weight gain by fish (kg)}}$$

$$5. \text{ Feed Conversion Efficiency (FCE, \%)} = \frac{\text{Gain in wet weight in fish (gm)} \times 100}{\text{Total weight of feed (gm)}}$$

$$6. \text{ Protein Efficiency Ratio (PER)} = \frac{\text{weight gain}}{\text{protien}}$$

### **3.8 Statistical Analyses**

Any mean differences among the treatments were analyzed using One Way ANOVA (P value of 0.05 set as a threshold), followed by a comparison of means using Tukey test. All statistical tests were done using SPSS (Version 27). Microsoft Excel (2013) for windows was used to create graphs. The requirements of normality of data and uniformity of variance across the groups were checked before the use of ANOVA.

## 4. Results

### 4.1 Water Quality Analysis

The essential water quality parameters such as water temperature and dissolved oxygen varied throughout the study period, with daytime temperature and dissolved oxygen ranging from 23.19 to 26.94 °C and 3.44 to 5.98 g/L respectively as shown in Table 5. In this study the mean water characteristics values of dissolved oxygen, temperature and pH were within the recommended levels as shown in Table 5 for rearing the African catfish.

**Table 5. Physicochemical parameters (DO and WT) recorded in experimental period**

Treatments	DO (mg/l)		WT (°C)		pH		Conductivity(µs/cm)	
	9:00	4:00	9:00	4:00	9:00	4:00	9:00	4:00
C	4.73±0.354	5.26±0.537	24.275±0.559	26.28±0.933	6.47±0.58	7.32±0.474	179.68±9.9	191.95±6.52
D1	4.195±1.07	5.32±0.933	23.91±1.018	25.98±1.032	6.51±0.51	7.37±0.566	178.995±7.049	190.78±9.998
D2	4.475±0.686	5.37±0.856	23.875±0.771	26.38±0.856	6.52±0.453	7.2±0.608	180.135±8.88	189.46±9.89
D3	4.365±0.856	5.277±0.771	24.255±0.544	26.31±0.771	6.57±0.34	7.26±0.474	182.71±13.774	191.99±6.731
P value	0.899	0.999	0.946	0.969	0.996	0.987	0.981	0.989

DO: Dissolved Oxygen, WT: Water Temperature

**Table 6. Physicochemical parameters ammonia (mg/l) recorded in experimental period**

Treatments	Ammonia(mg/l)	
	9:00	4:00
C	0.03±0.02	0.03±0.01
D1	0.03±0.01	0.04±0.01
D2	0.02±0.01	0.03±0.01
D3	0.03±0.01	0.04±0.01
P value	0.892	0.992

## 4.2 Mass production of Black soldier fly (*Hermetia Illucens*)

A Black Soldier's Life cycle under jimma environmental conditions, the lifespan of a fly from egg to adult is projected to be 40-43 days. Around 2.06 kg of BSF larvae collected all together from the combination of waste materials (poultry manure and brewery waste) and points within 4 months. After the egg hatched in to first instar larvae, the neonates measured their weight and feed given according to their weight (100gm feed was prepared from equal weight of poultry manure and brewery waste for 1gm of neonates). Cultivation period from egg to fifth instar stage of larvae was last for 3 weeks. Culture medium made of combination poultry manure and brewery waste 1:1 ratio at the feeding rate of 100gm/gm and biomass was determined by weighed the BSFL directly after harvested. BSFL was separated from the remaining medium, washed, and weighed. BSFL was dried under the sun for 3 days. Dried BSFL then weighed to determine the yield. Dried BSFL was linear with the number of biomass.

## 4.3 Growth performance of African catfish juveniles

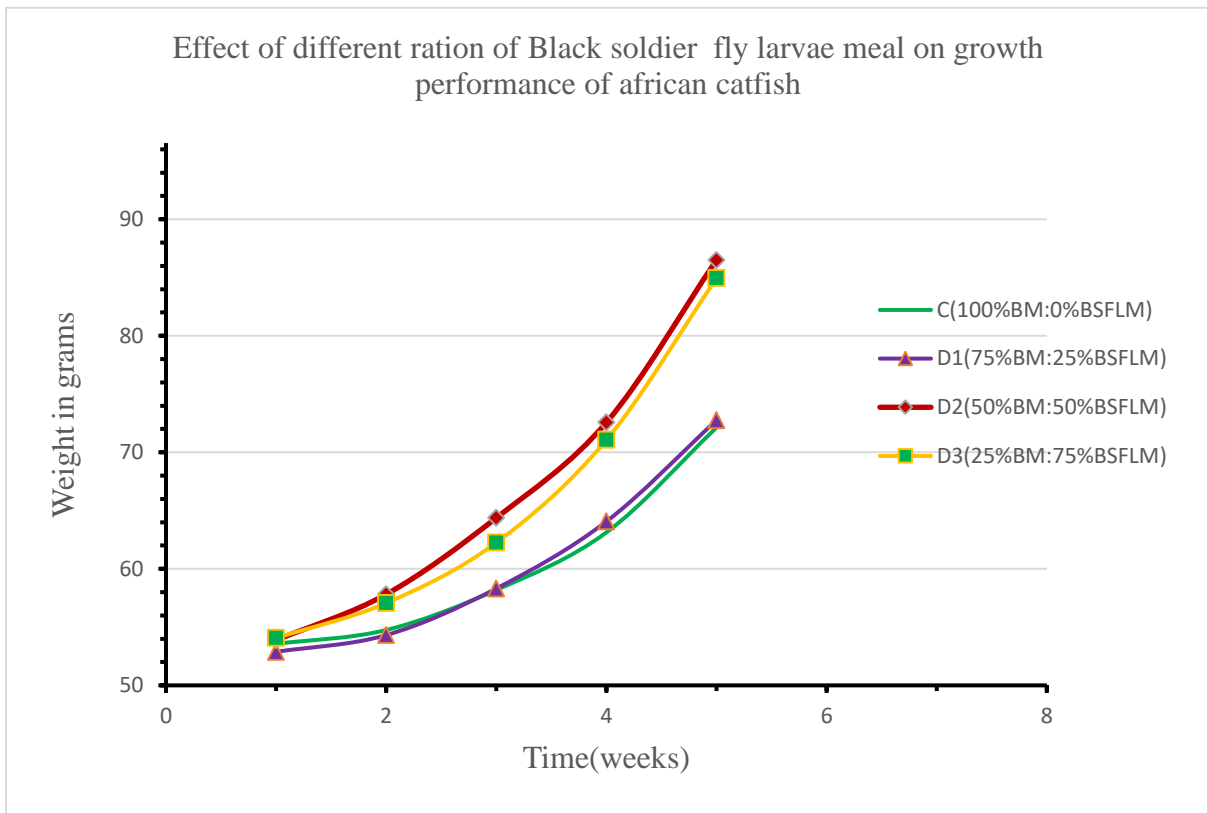
The cumulative growth data is presented in Table 8. The average body weight range between  $52.875 \pm 0.707$  and  $54.063 \pm 0.796$  g (Table 8) between groups of *C. gariepinus* at the beginning of the experiment and were not significantly different ( $P > 0.05$ ), indicating that groups were randomly divided and homogenous. 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 8

**Table 7. Mean cumulative growth rate and nutrient utilization parameters over the study period**

	C	D1	D2	D3
WI(gm)	$53.563 \pm 1.856^a$	$52.875 \pm 0.707^a$	$53.875 \pm 0.354^a$	$54.063 \pm 0.796^a$
WF(gm)	$72.125 \pm 1.414^b$	$72.75 \pm 0.354^b$	$86.5 \pm 0.061^a$	$84 \pm 0.884^a$
ADGR	$0.3094 \pm 0.0074^b$	$0.3313 \pm 0.0059^b$	$0.5438 \pm 0.118^a$	$0.5115 \pm 0.0103^a$
WG(gm)	$18.56 \pm 0.442^b$	$19.88 \pm 0.354^b$	$32.625 \pm 0.707^a$	$30.69 \pm 0.619^a$
SGR (%)	$0.496 \pm 0.025^b$	$0.516 \pm 0.008^b$	$0.789 \pm 0.009^a$	$0.753 \pm 0.016^a$
FCR	$72.57 \pm 1.81^a$	$69.32 \pm 1.954^a$	$45.73 \pm 0.829^b$	$47.51 \pm 1.28^b$
PER (%)	$53.04 \pm 1.26^b$	$56.79 \pm 1.01^b$	$93.21 \pm 2.07^a$	$88.21 \pm 1.01^a$

Means ( $\pm$ SE) values are for triplicate feeding groups. Means in the same row followed with different superscripts are significantly different ( $P < 0.05$ ). WI (weight initial), WF (weight final), ADGR (Average daily growth rate), FCR ( feed conversion ratio), PER (protein efficiency ratio),

WG (weight gain) C, Control diet (0% BSF larvae meal and 100% blood meal); D1, Diet 1 (25% BSF larvae meal and 75% blood meal); D2, Diet 2 (50% BSF larvae meal and 50% blood meal); D3, diet 3 (75% BSF larvae meal and 25% blood meal)



**Figure 5.** Weight gain of the catfish fed on different rations of black soldier fly larvae meals during the study period

**Table 8. Summary of the statistical analysis (one-way ANOVA) for the difference in the mean values of the parameters of fish feed on different diets**

Parameter		df	Mean Square	F	P value
Initial weight	Between different diets	3	.544	.463	0.724
	Within one diets	4	1.176		
	Total	7			
Final weight	Between different diets	3	111.654	110.788	< 0.001
	Within one diets	4	1.008		
	Total	7			
Average daily growth rate	Between different diets	3	.029	348.935	< 0.001
	Within one diets	4	.000		
	Total	7			
Weight gain	Between different diets	3	104.953	348.935	< 0.001
	Within one diets	4	.301		
	Total	7			
Specific growth rate	Between different diets	3	.047	182.670	< 0.001
	Within one diets	4	.000		
	Total	7			
Feed conversion ratio	Between different diets	3	398.938	169.101	< 0.001
	Within one diets	4	2.359		
	Total	7			
Gross feed conversion ratio	Between different diets	3	.138	5130.689	< 0.001
	Within one diets	4	.000		
	Total	7			
Protein efficiency ratio	Between different diets	3	867.618	449.727	< 0.001
	Within one diets	4	1.929		
	Total	7			

The lengths of the catfish juveniles were uniform during the stocking stages for all treatment diets as shown in Table 10 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 9. Mean length gain in centimeters of catfish fed on various BSF larvae inclusions over the study period (cm)**

Diet	Initial length	Final length	Length gain	ADGL
C	22.125 ± 0.530 <sup>a</sup>	28.25 ± 0.53 <sup>b</sup>	6.25 ± 0.884 <sup>c</sup>	0.1042 ± 0.0147 <sup>c</sup>
D1	22.000 ± 0.177 <sup>a</sup>	28.625 ± 0.177 <sup>b</sup>	6.625 ± 0.354 <sup>bc</sup>	0.1104 ± 0.0059 <sup>bc</sup>
D2	22.188 ± 0.088 <sup>a</sup>	31.313 ± 0.088 <sup>a</sup>	9.125 ± 0.177 <sup>a</sup>	0.1521 ± 0.0029 <sup>a</sup>
D3	22.313 ± 0.442 <sup>a</sup>	30.875 ± 0.354 <sup>a</sup>	8.563 ± 0.088 <sup>ab</sup>	0.143 ± 0.0015 <sup>ab</sup>
P value				

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% blood meal); D1, Diet 1 (25% BSF larvae meal and 75% blood meal); D2, diet 2 (50% BSF larvae meal and 50% blood meal); D3, diet 3 (75% BSF larvae meal and 25% blood meal)

#### 4.4 Proximate compositions of fish

**Table 10. Mean of proximate composition (% dry matter) of the analyzed carcasses harvested at the termination of the study (%)**

Parameter	Experimental fish carcass				P value
	BSFL 0%	BSFL 25%	BSFL 50%	BSFL 75%	
Dry matter	95.50±0.071 <sup>a</sup>	95.50±2.12 <sup>a</sup>	97.50±2.12 <sup>a</sup>	96.50±2.12 <sup>a</sup>	0.689
Crude protein	40.66±0.84 <sup>c</sup>	47.68±3.68 <sup>bc</sup>	58.04±2.00 <sup>a</sup>	51.74±1.02 <sup>ab</sup>	0.006
Crude fat	21±1.22 <sup>c</sup>	22.67±0.3 <sup>bc</sup>	24.56±0.42 <sup>ab</sup>	26.19±0.25 <sup>a</sup>	0.006
Ash	14.18±1.80 <sup>a</sup>	13.69±3.25 <sup>a</sup>	12.72±0.59 <sup>a</sup>	11.91±1.03 <sup>a</sup>	0.681
Fiber	0.1±0.14 <sup>d</sup>	0.31±0.21 <sup>c</sup>	0.48±0.21 <sup>b</sup>	0.6±0.14 <sup>a</sup>	0.001

## 5. Discussion

### 5.1 Feed trial using African catfish juveniles

With a mean total length of 9.0 – 9.4 cm TL and a mean total weight of 52.875 – 54.063 g across all treatment groups, the fish stocked of the trial were in the same size range (Table 7). However, there was a noticeable difference ( $p < 0.05$ ) in the final sizes of the fish between the treatment groups at the end of the trial. This indicates that the development of the fish was affected by the food they were given. The results of the growth experiment showed significant variations ( $p < 0.05$ ) in fish growth among the different treatments. Fish fed without BSFLM had the lowest daily growth rate (0.3094g/day), whereas fish fed 50% mashed BSFLM had the highest daily growth rate (0.5438g/day). This indicates that the growth rate of the fish was different with the level of BSFL replacement.

After eight weeks of commencement of the experiment, the average body weight gain shows significant difference ( $P < 0.05$ ), affected by the increasing dietary levels. The weight gain of fish fed different BSFL replacement fell into two groups. The group of fish fed on diet 1 and 2 which contains (0% BSFLM and 100% BM) and (25% BSFLM and 75% BM) respectively had lower body weight than the other treatments. Groups of fish fed on diets 3 and 4 which contain (50% BSFLM, 50% FM) and (75% BSFLM and 25% BM) respectively had higher weight gain values. The average weight gain (19.88 g) by the fish fed on diet that consisted of 25% BSFL was only slightly greater than the average weight gain (18.56 g) by the control group, which was statistically not significant ( $p > 0.05$ , Table 8) The group that fed on a diet with 50% BSFL showed the most significant increase in weight gain (32.63 g) compared to the control and 25% BSFL groups. This suggests a clear benefit of replacing half the blood meal with BSFL meal. The weight gain (30.69) by the fish that fed on a diet that consisted of 75% BSFL was still higher than the control but lower than the 50% BSFL group. There is no statistically significant difference in the weight gain by the fish that fed on the diet that consisted of 50% BSFL and 75% BSFL. According to Karapanagiotidis et al. (2014) 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. 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 results suggest that there is a significant impact on fish growth performance based on the different feeding regimes. When the diet consisted of 0% Black Soldier Fly Larvae (BSFL) and

100% basal diet, the weight gain was measured at  $18.56 \pm 0.442$  units. As the percentage of BSFL in the diet increased and the proportion of blood meal decreased, there was an improvement in weight gain. The results of this the investigation's growth performance were in close agreement with those of other previous experiments (Wen et al., 2013; Cummins et al., 2017; Zarantoniello et al., 2018), with the main differences being attributed to the different ages and species of fish used in the studies, as well as the fact that blood meal was the primary source of protein for fish feed in this study. Variations in the diet composition and formulation, as well as the conditions under which the fish were raised, may have also contributed to the inconsistent outcomes (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. Partial replacement of blood meal 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., 2007; Sealey et al., 2011). Higher levels of inclusion of BSF larvae meal has been thought to suppress digestibility of feeds and growth rates of fish reared. In contrast to the current study, which found that inclusion rates of 50% led to improved weight gain of the African catfish, weight gain in the rearing of 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. Dumas et al. (2018) reported that use of BSF larvae meal in the rearing of rainbow trout enhanced growth as the thermal growth coefficient increased with each increase in unit of BSF larvae meal, 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 blood meal.

The present study indicated that inclusion of BSF larval meal at 50% and 75% rates increased growth performance, in contrast to Vargas et al. (2019) who stated that clownfish fed BSF larvae meals did not perform any differently from the control treatment diet without BSF larvae meal. According to Renna et al. (2017), rainbow trout raised on BSF larvae meal at inclusion rates of 50% did not experience adverse growth rates. This is consistent with the findings of the current study, which showed that diet D2 (50% BSF larvae meal) had significantly higher ( $P < 0.05$ ) weights than the control diet C (0% BSF larvae meal). In the rearing of Siberian sturgeon, BSF larvae meal was used as a test ingredient at 15% inclusion rates. Józefiak et al. (2019) reported that growth rates were not negatively affected, which is consistent with the current study's findings that the inclusion of the test ingredient did not negatively affect the growth in treatment diets of D2 and D3. 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). The increased chitin content of the BSF larval food may have contributed to the current study's lower feed conversion ratios (FCR) when compared to prior research. Chitin is found in the exoskeletons of insects. Due to the absence of the enzyme chitinase (Rust, 2002; Cummins et al., 2017) and the proper gastro-intestinal tract microbiota, particularly bacteria, most fish species (Smith et al., 1989; Esteban et al., 2001; Kroeckel et al., 2012; Henry et al., 2015; Magalhaes et al., 2017; Renna et al., 2017) are unable to easily digest chitin.

Although Jian carp performed better under the same feeding regimes, it has been found that the proximate chitin levels of most insect meals range between 11.6 and 137.2 mg/kg in DM (Finke, 2007). As a result, treatment D3, which contains high levels of BSF larvae meal, may negatively affect the growth rates of African catfish. The results of the Ng et al. (2001) study support the findings of the current study on African catfish, which showed that using mealworm larvae (*Tenebrio molitor*) improved the fish's growth, feed conversion efficiency, and overall nutritional qualities. The growth performance and feed utilization parameters, including ADGR, WG, SGR, PWG, FCR and PER an improvement was observed as a consequence of increasing BSFL incorporation into the diets.

## **5.2 Proximate compositions of fish**

In this study whole-body proximate composition of fish was affected by the BSFL inclusion as the fish meal replaced the diets. The proximate analysis on carcasses indicated that fish fed on D2 (BSFL meal was 50%) had the highest crude protein at 58.04% while control group had the lowest at 40.66%. Treatment diets D2 and D3 had significantly ( $P < 0.05$ ) higher crude protein levels whereas diet control group had significantly lower levels of crude protein as shown in Table 11. The percentage CP of the carcasses in treatment diets D2 was significantly higher ( $P < 0.05$ ) than in all the other treatment diet carcasses. Previous studies, like the one conducted by Katya et al. (2017), concluded that the incorporation of BSFL in the rearing of juvenile Barramundi, *Lates calcarifer*, did not affect the composition of the carcasses; other investigations have also revealed no significant differences in the whole-carcass chemical composition, particularly concerning the percentage CP of trout fed varying amounts of BSF larvae meal (StHilaire et al., 2007a; Zarantoniello et al., 2018). While Zarantoniello et al. (2019) reported that rearing zebrafish using BSF larvae meal did not negatively affect the proximate composition of the harvested carcasses; Cummins et al. (2017) found that the nutrient proximate composition of shrimp carcasses was not significantly influenced with different feeding levels with dietary BSF larvae.

Increased BSFL meal consumption in diets is associated with a marked reduction in feed intake and, consequently, a reduced intake of carbohydrates. Because of the reduced feed intake and thus poor energy intake, Kroeckel et al. (2012) observed a drop in gross energy content with higher quantities of housefly maggots. Because BSFL has a high fiber content (Mulianda et al., 2020), increasing the amount of BSFL meal inclusion in the diets increased the crude fiber content of the whole body composition. While some studies reported that BSFL contained chitin at 8.7% dry matter (Diener et al., 2009) and 9.6% dry matter (Kroeckel et al., 2012), it's possible that the increase in BSFL meal in the experimental diets increased the proportion of chitin per unit of dry matter (Zhu et al., 2016), which was absorbed by the fish. This result of the current study also consistent with those of Mapanao et al. (2021), who observed an increase in crude lipids of Thai climbing perch (*Anabas testudineus*) that were fed diets containing BSFL meal up to 100%. However, other studies found that in rainbow trout, the crude lipid content of the whole body and muscle tissue decreased significantly as the amount of BSFL increased. The whole-body fish ether extracts increased significantly with a corresponding increase in the dietary insect meal inclusion. This finding also agrees with those of Rana et al. (2015), Muin et al. (2017), Teye-Gaga (2017), and Devic et al. (2018), who reported an increase in body crude fat content and saturated fatty acid content in Nile tilapia (*Oreochromis niloticus*) fry, fingerlings (Sealey et al., 2011; Kroeckel et al., 2012). These researches suggested that the defatting process influences the level of the lipids and that this may have reduced the lipid bioavailability (Kroeckel et al., 2012). The present investigation additionally revealed that the incorporation of BSF larvae meal in the various experiment diets had no significant impact on the ash content of carcass chemical analysis of the catfish;

The results of the current study show that use of BSF larvae meal in the rearing of the African catfish affects 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).

## **6 Conclusion and recommendation**

### **6.1 Conclusion**

This study revealed that growth and nutrient utilization of fish varies with levels of black soldier fly that can be utilized as a potential alternative to blood meal in the diets of African catfish, *C. gariepinus*. Basal diet that consisted of the local fish fed ingredients can be replaced with black soldier fly larvae in the diet of African catfish up to 75%, without adverse effect on growth. Nearby 50% replacement of basal diet with black soldier fly is the recommendable level of incorporation of black soldier fly for best growth performance African catfish juveniles.

### **6.2 Recommendation**

1. Further studies to determine of the efficacy of the BSF feed on different kinds of fish such as the carnivorous fish types and when supplemented with premixes of lacking nutrients
2. A study to determine the nutrient content of BSFL fed on different organic substrates in terms of amino acid and fatty acid content to facilitate more accurate use of larvae in feed making.

## 7. References

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## Appendix 1: Eggs on eggies



## Appendix 2: Adult BSF in the love cage



### Appendix 3: processing of fish for detrainin carcass nutrients



## Appendix 4: during length weight measurement



## Appendix 5: feed formulation



## Appendix 6: harvesting of larvae



## Appendix 7: four diet used for the study

