EFFECTS OF BLACK SOLDIER FLY (*HERMATIA ILLUCENS* BURCHELL, 1822) LARVAE BASED DIETS ON GROWTH PERFORMANCE, CARCASS COMPOSITION AND ECONOMIC EFFICIENCY OF AFRICAN CATFISH (*CLARIAS GARIEPINUS* LINNAEUS, 1758)

By

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DECLARATION AND APPROVAL

Declaration

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

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This project is dedicated to my family for unwavering support and confidence in me during my degree program.

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ABSTRACT

The aquaculture industry is often considered as the future solution to the dwindling wild fish capture. The expansion of aquaculture faces a significant obstacle in the form of inadequate fish output due to lack of affordable quality feeds. In sub-Saharan Africa, fish feed protein ingredients are among the most expensive and often unavailable of all feed ingredients. Fishmeal is the primary source of protein for fish feeds in Kenya’s aquaculture industry; however, it is expensive and is sometimes tainted, which leads to a reduction in the industry’s overall productivity. Due to this issue, there is a pressing need to investigate alternative protein sources that are less costly and more readily available, such as the Black soldier fly larvae meal. A 12-week feeding experiment was done to evaluate effects of replacing fishmeal with black soldier fly larvae meal on growth performance, carcass composition and economic efficiency of African Catfish (*Clarias gariepinus*). Five isonitrogenous (40% crude protein) and isolipidic (8% ether extracts) feeds were formulated to replace 0% (control), 25%, 50%, 75% and 100% fishmeal with black soldier fly larvae meal. A Randomized Complete Block Design was used and 600 fingerlings (0.46±0.02g) were randomly selected and stocked at a density of 40 fingerlings in 15 circular plastic tanks in triplicates. Fish were fed twice a day at 6% body weight. Results showed that the treatment diets significantly ($p<0.05$) affected the growth performance indices, feed intake and utilisation indices, and carcass composition of the fish. Furthermore, 25% fishmeal could be replaced by black soldier fly larvae meal without significantly reducing feed intake, feed utilisation efficiency indices and growth indexes. There was no evidence of significant variations in water quality between treatments ($p>0.05$). A decreased concentration of crude protein, ash, nitrogen free extracts in carcass composition of fingerlings with a corresponding increase in dietary black soldier fly larvae meal inclusion, was observed. Increasing inclusion levels of black soldier fly larvae and decreasing levels of fishmeal, increased concentration of ether extracts and fibre contents of the body composition. Results also showed that feeding the African catfish fingerlings with black soldier fly larvae-based diets reduced significantly ($p>0.05$) the incidence cost compared to those fed on black soldier fly larvae 0%. From the results black soldier fly larvae 0% had the highest incidence cost (KES 99.99) while black soldier fly larvae 100% (KES 59.93) had the lowest incident cost. Black soldier fly larvae-based diets significantly increased ($p<0.05$) the profit index compared to those fed on black soldier fly larvae 0% and black soldier fly larvae 100% and 25% had the highest profit index of (KES 5.06) and (KES 4.28) respectively. The present experiment recommended partially replacement of fishmeal up to 25% in order to improve feed utilization, growth performance, carcass composition, and the profit index and further field trials.

Keywords: Carcass composition; economic analysis; feed utilisation; fishmeal; insect meal; proximate analysis

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LIST OF ABBREVIATIONS AND ACRONYMS

ABDP	Aquaculture Business Development Programme
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BSF	Black Soldier Fly
BSFL	Black Soldier Fly Larvae
Ca	Calcium
Cm	Centimetre
RCBD	Randomised Complete Block Design
CF	Crude Fibre
CP	Crude Protein
DM	Dry Matter
DO	Dissolved Oxygen
EE	Ether Extracts
FAO	Food and Agriculture Organization of the United Nations
FCR	Feed Conversion Ratio
FI	Feed Intake
FBW	Final Body Weight
FFEPP	Fish Farm Enterprise Productivity Programme
FM	Fishmeal
g	Gram
GLM	Generalised Linear Model
GoK	Government of Kenya
h	Hour
H_2SO_4	Sulphuric Acid
HFMM	House Fly Maggot Meal
IBW	Initial Body Weight
IFAD	International Fund for Agricultural Development
JOOUST	Jaramogi Oginga Odinga University of Science and Technology
KNBS	Kenya National Bureau of Statistics
Kg	Kilogram
K_n	Relative Condition Factor
KES	Kenyan Shilling

L	Litre
LSD	Least Significant Difference
MFL	Mean Final Length
MFW	Mean Final Weight
mg	Milligrams
MIL	Mean Initial Length
MIW	Mean Initial Weight
ml	Millilitre
mm	Millimetre
MWG	Mean Weight Gain
MUFA	Monounsaturated Fatty Acids
N	Nitrogen
NFE	Nitrogen Free Extracts
NH_3	Ammonia
NRC	National Research Council
PER	Protein Efficiency Ratio
PI	Protein Intake
pH	Potential of Hydrogen Ions
PUFA	Polyunsaturated Fatty Acids
SFA	Saturated Fatty Acids
SR	Survival Rate
SGR	Specific Growth Rate
USD	United States Dollar
WG	Weight Gain

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The increase in demand for fish globally as a source of protein, has made the aquaculture industry to grow in leaps and bounds over the recent decades. Indeed the aquaculture industry has developed significantly over recent decades and is one of the fastest growing food production sectors in the word compared to other food commodities with an annual increase of approximately 12% (FAO, 2009). This rapid expansion of the aquaculture industry is due to the rise in human population, which has led to an increase in the consumption of fish and fishery products (GoK, 2010b; FAO, 2012). In both developing and developed countries, fish and its products helps in improving the nutrition and food security of people (FAO, 2014). Further, fish is also an important source of high-quality protein and it contains all essential amino acids, minerals and micronutrients (FAO, 2012).

According to Gatlin *et al*. (2007), one in every three fish that is consumed by humans worldwide is farm bred. Fish provides more than 1.5 billion people with roughly 20% of their average per capita intake of animal protein as well as 3 billion people with 1 percent of that protein (FAO, 2011). The global human population is expected to reach 9 billion people by the year 2050 (FAO, 2012; 2014; Kobayashi *et al*., 2015), whereas the fish population from capture fisheries is believed to remain the same or decline (Rana *et al*., 2009). Increasing production capacity of aquaculture is widely acknowledged as a potential solution to the ever-rising demand for fish from the world's growing human population (Tidwell, 2012; Kirimi, 2019).

The global share of aquaculture fish production increased gradually from 7 percent in 1973 to 12 percent in 1985 to over 30 percent by the year 1997 (Delgado *et al*., 2003).Since 1998, the world aquaculture output has increased at an average yearly pace of 9.7 percent and it reached 59 million tonnes in the year 2010 (FAO, 2012). In 2012, the global aquaculture output was reported to have increased from 59 million tonnes in 2010 to 66.6 million tonnes (FAO, 2014). The global output of fish from aquaculture increased to 73.8 million tons in 2014, accounting for 46.9% of the overall production of fish from aquaculture and capture fisheries as compared to 42.1% in 2012 (FAO, 2017). Sub-Saharan Africa's aquaculture growth was 10.4% on averaged between the years 2001 and 2015 (FAO, 2017).

More than seventy percent of fish and fish products that are consumed locally in Kenya come from wild capture fisheries, for which most of them are from Lake Victoria (Matanda *et al*., 2017). However, as a result of the implementation of the Fish Farm Enterprise Productivity Programme (FFEPP) in 2009, the aquaculture industry has become the fastest growing subsector, thereby improving fish production in Kenya (GoK, 2010a). The Government of Kenya (GoK), with funding from the International Fund for Agricultural Development (IFAD), is supporting smallholder aquaculture fish production through another program called the Aquaculture Business Development Programme (ABDP). The goal of this support is to boost aquaculture production and trade within the country by actualising the productive potential of smallholder farmers. According to Munguti *et al*. (2014), the Kenyan aquaculture production industry has increased significantly over the past decades, from 1,012 metric tons of fish in the year 2003 to 21,487 metric tons in the year 2012. In the year 2013, the total amount of fish produced in Kenya was 152,711 tons, with aquaculture accounting for 23,501 tons or 14% of that total fish production (KNBS, 2014). However, even though there was a significant increase in Kenyan aquaculture production, the productivity in terms of fish output dropped by 19.8% from 18,656 tons in 2015 to 14,952 tons in 2016 (World Bank, 2017).

Despite the widespread adoption of aquaculture farming in many parts of Kenya, the most significant challenge continues to be the high cost of feeds (Kirimi *et al*., 2016). Rahman *et al*. (2013) observed that in order to ensure the long-term viability of the aquaculture production, there has to be a matching rise in the production of diets specifically suited for the aquatic animals. The formulation and management of fish diets is a major factor that determines the profitability and viability of the aquaculture enterprise (Gabriel *et al*., 2007). In aquaculture, the key most expensive component is nutrition, which under current economics accounts for more than 50-70% of the variable costs (Agbo, 2008; Nguyen *et al*., 2009).

When taking other animals into consideration, it is known that aquaculture is the single largest consumer of fish meal and it uses more than 53% of the global supply (Tacon, 2004; Tacon *et al*., 2006). The swine and poultry industries together account for only a quarter of the total fishmeal usage, while the remainder is being utilised by other livestock species. About 36% of the total global fisheries are being harvested each year and crushed up into fishmeal and oil to produce feeds in aquaculture and livestock industries (Jacquet *et al*., 2010). Fishmeal is used in aquaculture diets to feed both the omnivorous and carnivorous fish species at levels more than 50% especially in carnivorous fish species and being overly dependent on one ingredient can bring some risks (Tacon 1993; Glencross *et al*. 2007). Fishmeal is regarded as the key component of animal protein ingredient used in formulation of aquaculture diets due to its high-quality protein content (60 - 70% crude protein), balanced amino acid profile, minerals, high palatability and digestibility as well as very low levels of anti-nutritional factors (Watanabe *et al*., 1997; Zhou *et al.,* 2006; Haghbayan & Mehrgan, 2015). Despite that most fish meet the qualities of the nutritional requirements above, fishmeal is regarded as an expensive component and it contributes significantly to the rising costs of production in aquaculture enterprises (Nguyen *et al*., 2009; Ayoola, 2010).

Ogello *et al.* (2014) pointed out that the rapidly declining status of the global fisheries and the corresponding increase in aquaculture production exposes a debate as to whether it is suitable or not to feed fish on fish meal hence the development of sustainable aquaculture relies on the establishment of alternative ingredients to fishmeal (Makinde and Sonaiya, 2012). Due to the high price of fishmeal, the production of fish for commercial purposes requires a significant investment of capital and accounts for between 30 and 60 percent of variable operating costs (De Silva and Anderson, 1995). As a result, there is an urgent need to investigate alternative protein feed sources (Sales & Janssens, 2003). Tacon. (1993) and Glencross *et al*. (2007) also indicated that a way of reducing the danger of over dependence on fish meal is to identify, develop and use alternative protein sources. Usually, the strategy that has been adopted in order to reduce the feed costs has been to formulate low-cost feeds which can favourably replace expensive feeds containing fish meal with cheaper feeds containing insect or plant protein sources without disturbing the growth and health of fish (Sogbesan & Ugwumba, 2008).

In search of alternative quality protein for fish feeds, much attention has been paid to the use of insects (Limbu *et al*., 2022). Insects have the required nutritional quality

(Nowak *et al*., 2016) and are consumed naturally by various animals including fish, wild birds, and free-ranging poultry (Fiaboe & Nakimbugwe, 2014). In this regard, the larvae of Black Soldier Fly (*Hermetia illucens* Linnaeus, 1758) (BSFL) is one of the promising alternative protein source that can replace fishmeal as a low-cost nutrient-rich ingredient for aquafeeds production (Caimi *et al*., 2021). The BSFL is capable of converting organic waste into food, generating value and closing nutrient loops as it reduces organic pollution and their subsequent management costs as compared to other insects (Wang & Shelomi, 2017; Chia *et al*., 2019). BSFL meal has been used successfully to replace fishmeal in diets for various fish species such as Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) (Devic *et al*., 2018; Limbu *et al*., 2022); Jian carp (*Cyprinus carpio* Linnaeus, 1758 var. Jian) (Zhou *et al*., 2018) and Rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) (Elia *et al*., 2018; Terova *et al*., 2019). However, there is still limited information regarding the use of BSFL meal on the growth and carcass quality of African catfish (*Clarias gariepinus* Burchell, 1822) (Talamuk, 2016), which is one of the common fish species cultured in fresh water bodies (Matanda *et al*., 2017). The African catfish is one of the choice culture species due to its high demand, rapid growth and high productivity, and fair prices (De Silva and Davy, 2011; Engle *et al*., 2022). The present study was therefore, conducted to assess the use of BSFL meal as a partial or complete replacement for dietary fishmeal on the growth performance, carcass composition and economic efficiency of African Catfish (*C. gariepinus*).

1.2 Statement of the Problem

Currently in Kenya, commercial fish feeds are one of the most expensive animal feeds being sold on the market (Kirimi, 2019). This high cost of aquaculture feeds is attributed to high levels of protein, which come mostly in the form of fish meal. Fish meal is the key ingredient in aquaculture diets yet it is the most scarce and expensive. In Kenya the retailing price for fish meal was KES 250 kg^{-1} in 2018 (Biketi *et al*., 2018). The scarceness of fish to produce fish meal is attributed to the shift in dietary patterns among people and the imperative to consume a diet that is nutritionally sound. The increase in demand for fish meal is also a result of the growing aquaculture industry, a decline in the number of wild fish captures, and the formulation of various types of animal feeds, particularly in the poultry and pig industries. Regardless of the high cost of fish meal, its inclusion in the animal and aquaculture feeds is unavoidable due to its balanced amino acid profile, high-quality protein content high palatability and digestibility as well as a source of energy, minerals and n-3 polyenoic fatty acids

Since the majority of farmers are not able to afford such expensive fish feeds, one sustainable solution to curb this problem is to use non-conventional feed resources that can help to meet the nutritional requirements of fish. Plant-based protein sources such as sunflower, and soya bean meal can also be used as alternative protein sources. However, they do have a number of drawbacks, the most significant of which include: low protein content, unbalanced essential amino acid profile as well as limited availability of minerals. Furthermore, these plant protein sources such as soya bean production has not been quite successful in several parts of Kenya due to the erratic rainfall patterns and drought, which has affected yields and as a result, availability of the raw materials on the local market (Kirimi, 2019). Fish feed manufactures therefore are relying on imports from countries such as Uganda and Tanzania in order to meet the demand of feed in the country. This has led to the increase in raw material costs and in turn, higher prices of fish feed. Most small-scale farmers and particularly in the rural areas cannot afford buying commercial feed for fish, which lowers productivity in the aquaculture sector. One of the promising alternative sources of protein in fish diets formulation is the Black Soldier Fly Larvae (BSFL), and this strategy offers an additional benefit of reducing organic waste. Thus, the present study aimed at evaluating BSFL meal as a potential ingredient to replace fishmeal in African catfish rearing.

1.3 Objectives

1.3.1 General Objective

To evaluate the performance of African Catfish fed on various inclusion levels of black soldier fly larvae-based diets.

1.3.2 Specific Objectives

The specific objectives of this study were to:

1. Determine the effect of BSFL based diets on growth performance of African Catfish (*C. gariepinus*).
2. Determine the effect of BSFL based diets on carcass composition of African Catfish (*C. gariepinus*).
3. Compute the overall cost of production of African Catfish (*C. gariepinus*) based on the levels of replacement of fishmeal with BSFL.

1.4 Hypotheses

The null hypotheses that were tested are:

H_{01} Black soldier fly larvae-based diets have statistically no significant effect on growth performance of African Catfish (*C. gariepinus*).

H_{02} Black soldier fly larvae-based diets have statistically no significant effect on carcass composition of African Catfish (*C. gariepinus*).

H_{03} The level of replacement of fishmeal by BSFL in the diet has statistically no significant effect on overall cost of production of the African Catfish (*C. gariepinus*).

1.5 Justification of the Study

The food and nutrition situation in Africa epitomizes food insecurity among households (The African, 2009), while in both developing and developed countries, fish and its products contributes much in improving the nutrition and food security of people

(FAO, 2014). Fish plays a major role in human nutrition in terms of the needed vitamins, minerals, and other micronutrients, as well as the high-quality protein. Kenya became one of the greatest economies in Sub-Saharan Africa in October 2014, passing the threshold from a nation with a low income to a country with a low and medium income. Nevertheless, problems such as poverty and income disparity continue to be a problem, and the government of Kenya's primary focus continues to be food security (IFAD, 2014). The global hunger index indicates that Kenya is still a food insecure country, despite the fact that there have been some improvements in the overall situation on hunger. Statistics estimated that over 10 million people in Kenya are affected by persistent food insecurity and inadequate nutrition (IFAD, 2014). In Kenya, the agricultural sector is considered the backbone of the economy and a majority of Kenya's rural population relies on agriculture as their livelihood. Over 2.3 million people depend on working in the fishing industry for their primary source of income, giving the business a significant impact on the economy as a whole (GoK, 2010a; Aloo-Obudho & Magret, 2010). In spite of the fact that the contribution of the fish industry to the Gross Domestic Product (GDP) of Kenya is only estimated to be 0.5%, this is likely to rise above 5% if all of the production and value addition inputs are considered (Aloo-Obudho & Magret, 2010) and in the years to come aquaculture production is believed to make a major improvement in households food security and foreign currency earnings (FAO, 2012). A combination of factors, including Kenya's expanding population and the country's transition toward a more health-conscious way of life, has led to an increase in the demand for fish (GoK, 2010a). Since the beginning of the economic stimulus program in 2009 and the identification of aquaculture as a key sub-sector for addressing food insecurity problems among households, there has been an enormous growth in this sub-sector; however, one of the most challenging issues in Kenya is the lack of high quality and cost-effective aquafeeds (Charo-Karisa & Gichuri, 2010).

Therefore, the appropriate selection of alternative protein sources for the formulation of fish meals might be the solution to this problem and insect-based protein sources such as Black soldier fly larvae meal (BSFL) provide the ideal alternatives to fishmeal. The nutritional profile of BSFL is favourable, and preliminary researches have shown that it can be incorporated in commercial fish feeds by partially or completely replacing conventional fish feed ingredients such as fishmeal (Rumpold & Schlüter, 2013). BSFL meal has shown to be an excellent protein source for various fish species as shown in previous researches for Channel catfish (*Ictalurus punctatus* Rafinesque, 1818), Rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792), Turbot (*Scophthalmus maximus* Linnaeus, 1758), White shrimp (*Fenneropenaeus merguiensis* de Man, 1888) (Cummins *et al.*, 2016) and polyculture of Channel catfish with Tilapia (Bondari & Sheppard, 1981) .

This study forms an important area of research to determine the effect of BSFL (*H. illucens*) meal on growth performance, carcass composition and economic efficiency of African Catfish (*C. gariepinus*). Once the in-depth knowledge of the impact of BSFL on African Catfish production is determined, the aquaculture industry can adopt the suitable formulation, commercialize it and then thrive, particularly in the smallholder sector.

1.6 Scope of the Study

The expansion of the aquaculture industry is dependent on the affordability and availability of fish feeds. Fish meal is the prominent ingredient in the aquaculture industry; however, it is not sustainable because of the scarceness of the resource and rising costs. Exploring alternatives ingredients is an option among nutritionists to produce high quality feeds at feasible cost. In order to supplement or replace the traditional protein source, black soldier fly might be introduced to the feed sector. Thus, the purpose of this study is to determine the effect of black soldier fly larvae-based diets on growth performance, carcass composition, and economic efficiency of African catfish. The study was conducted at Jaramogi Oginga Odinga University of Science and Technology, Main Campus, Kenya for a period of twelve weeks.

1.7 Limitations of the Study

Sourcing of African catfish seed (fingerlings) was initially a challenge that was overcome by acquiring them from a neighbouring county, far from the study site. Adaptation of the fingerlings was difficult and the first batch of fish died, and the whole set had to be replaced from another supplier of fingerlings. Another limitation was the water used to culture the experimental fish. The water was chlorinated and had to be conditioned for a couple of days to dechlorinate it before use in the experiment. Another major challenge was the use of manual culture system during the experiment because there was no water recirculating system, consequently, a manual method was used in siphoning and replenishing water in the experimental tanks using hose pipe. Limitations in laboratory analysis was addressed through collaboration with another well-equipped university for nutritional analysis.

1.8 Definition of Terms

Aquaculture – The farming of aquatic organisms, which takes place either in inland or coastal areas

Feed conversion ratio – The conventional measure of livestock production thus weight of feed intake divided by weight gained by the animal

Growth performance – The increase in body weight per unit of time

Iso-nitrogenous diets – Diets with similar amount of dietary nitrogen or protein

Null hypothesis – A claim that there is no relationship exists between two sets of data or variables being analysed

Protein efficiency ratio – The ratio of grams of body weight gain (in specified time) to the grams of protein consumed

Proximate analysis – A method used to determine the chemical composition or components of food or feed ingredients available**.**

Relative condition factor – An indicator of the leanness/fattiness of a fish, which is generally regarded as an indicator of fish´s health

Specific growth rate – A coefficient that measures the percentage increase in fish weight per day.

Stocking density – Total fish biomass per unit of tank volume

Water quality – The total sum of chemical, biological as well as physical characteristics of a water body.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of the Current Global Fisheries and Aquaculture Production

Aquaculture is the farming of aquatic organisms, which takes place either in inland or coastal areas. It involves the manipulation of the rearing process in order to increase production, and the ownership of the stock being cultivated and can be held by either an individual or a corporation (FAO, 2009; Kirimi, 2019). The global fish output has increased consistently over the past five decades, with food fish supplies growing at an average annual rate of 3.2 percent, exceeding the increasing world population, which is currently at 1.6 percent (FAO, 2016). According to FAO (2022), the overall global aquaculture and fisheries production reached 214 million tons in 2020, comprising of 178 million tons of aquatic animals with the major growth being produced from aquaculture.

Globally, the annual human per capita fish consumption significantly rose by double from an average of 9.9 kg in the 1960s to 20.2 kg in 2020 (FAO, 2022) for which aquaculture contributed about 46 percent of the total production and 52% of the fish were consumed by people (FAO, 2020b). According to FAO (2022), this remarkable increase in fish production (Fig 2.1) has been accelerated by increase in world population, urbanization, and rising affluence, and it has been made possible by an increase in fish output as well as more efficient distribution systems (FAO, 2014). In this sense, the expansion of global aquaculture production is mostly driven by the world's expanding population, which is expected to reach approximately 9 billion by the year 2050. (FAO, 2012; 2014; United Nations, 2015). In the past, people believed that the oceans contained an infinite amount of fish and that there would always be enough to satisfy an ever-growing human population. However, the ever-increasing human population will still create a huge demand on aquaculture as well as the few surviving capture fisheries. Aquaculture is often regarded as the most effective strategy for closing the supply-and-demand mismatch in the fish industry (Agbo, 2008).

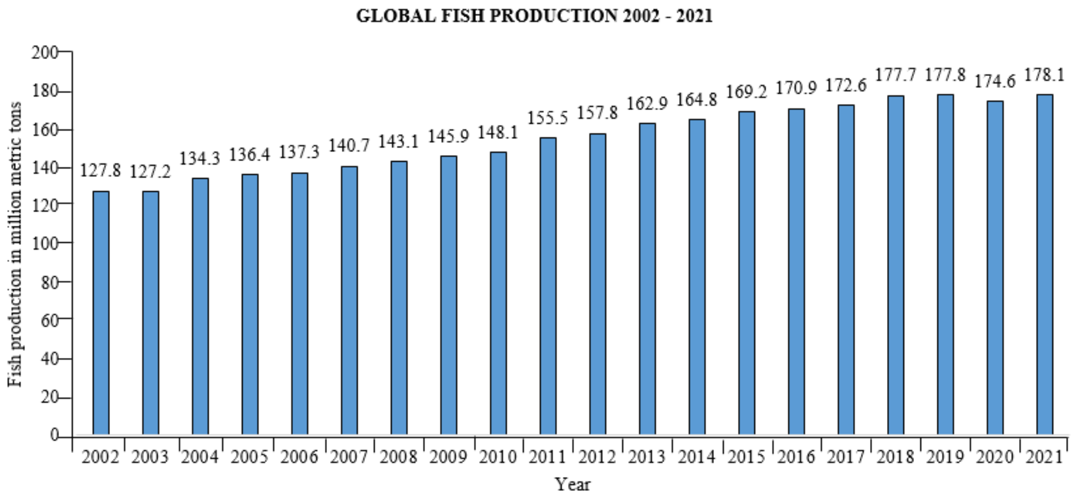

Figure 2.1: Global fish production from 2002 – 2021 (Source: FAO, 2022)

2.2 Overview of Aquaculture in Sub-Saharan Africa

In Sub-Saharan Africa, aquaculture started around 1950s with the goals to improve nutrition of people living in rural areas, diversity of farming operations in order to minimise crop failure risks, creation of employment to rural people and generating additional income (Hecht, 2006). FAO (2020a) reported that in 2018 the Sub-Saharan Africa's contribution to the world's aquaculture production was very small, accounting for only 0.62 percent of the total. However, between the years 2008 and 2018 total aquaculture production in Sub-Saharan Africa significantly increased from 359,000 tons to 719,000 tons respectively. This resulted in average annual growth rates of around 12 percent from 2008 to 2015, which significantly increased the global average growth rate for aquaculture production during the period (FAO, 2020a). However, between the years 2015 and 2018, there was no growth in aquaculture output due to a decline in the production of seaweed and a growth rate that was far lower than anticipated in major finfish producing countries such as Kenya, Nigeria, and Uganda. In spite of this, the value of the entire production at the farm gate in 2018 was USD 1.70 billion, which was an increase from USD 714 million in 2008 as shown in figure 2.2 below.

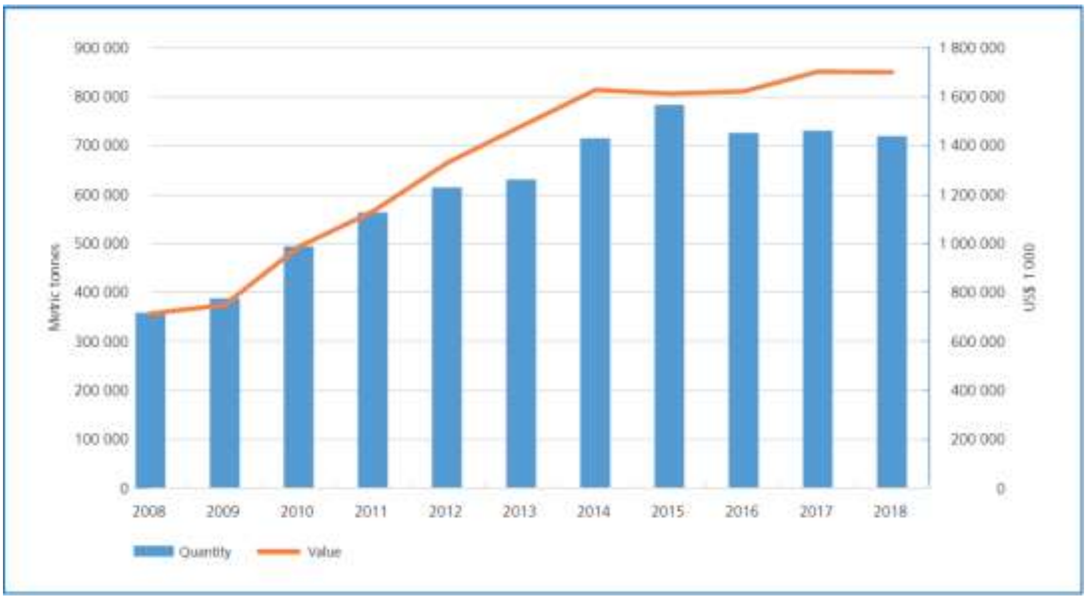

Figure 2.2: Aquaculture production volume and value in Sub-Sahara Africa (Source: FAO, 2020a)

In 2018, the Western Africa region was the highest in production volumes of aquaculture (excluding aquatic plants), and it contributed to 63% of the total Sub-Saharan Africa aquaculture production followed by Eastern African region which had 32% as well as Northern Africa (Sudan) and Southern Africa accounting for 2% each, and the Central Africa with 1%.

In Sub-Saharan Africa, Nigeria has been consistently the leading aquaculture producing country (FAO, 2017) and in 2018 it accounted for about 48% of the total regional aquaculture output compared to 60% of the year 2008 which reflected growth in other countries (FAO, 2020a). The other main aquaculture producers in the region include Zambia, Uganda and Ghana and in 2018 these four countries contributed about 82% of the total aquaculture output. Over the past five years a significant growth in aquaculture production has been noticed among the major producers thus Malawi, Ghana, United Republic of Tanzania, Rwanda and Zambia as shown in (Table 2.1). This remarkable growth was attributed to investments from the private sectors, involvement of private-capacity building and emphasis on research, adoption of good governance, availability of feeds, use of new production systems such as cages, implementation of sound management systems and establishment of efficient commercial hatcheries (FAO, 2017). However, the aquaculture production growth seems to have declined in Uganda while in Zimbabwe, Nigeria and South Africa it did not change.

Table 2.1: Total African aquaculture production volume by region in 2008 and 2018 (including aquatic plants)

Country/ Area	**Tonnage**	
	2008	**2018**
World	70 203 425	114 508 041
Africa	1 061 953	2 308 673
Sub-Saharan Africa	358 948	719 013
West Africa	152 106	384 876
Eastern Africa	196 657	305 094
Southern Africa	6 117	10 956
Northern Africa (Sudan)	-	10 000
Middle Africa	4 067	8 087
Top 10 Aquaculture countries/territories (by quantity) in Sub-Saharan Africa		
Nigeria	143 207	291 323
Uganda	52 250	103 737
United Republic of Tanzania, Zanzibar	107 925	103 234
Ghana	5 594	76 630
Zambia	5 640	24 300
United Republic of Tanzania	5 217	16 852
Kenya	4 452	15 524
Madagascar	14 486	12 758
Zimbabwe	2 652	10 586
Sudan	-	10 000
Malawi	1700	9 014

(Source: FAO, 2020a)

2.3 Overview of Kenya's Aquaculture Production

2.3.1 Development of Aquaculture in Kenya

The Colonial Government was the first to initiate aquaculture in Kenya around 1920s where they introduced tilapiines and later on the Common Carp and African catfish (Vernon and Someren, 1960). Aquaculture was then promoted in the years between 1940s and 1960s, as a source of sustainable food with the objective of improving nutrition to people in remote areas, diversification of farming enterprises in order to reduce the risk of crop failures, creation of employment for rural people and generating additional income (Adeleke *et al.*, 2020). In 1948 the colonial government then established the Sagana and Kiganjo fish farms in order to produce warm water tilapia and cold water trout (GoK 2010b). After independence, the newly formed government then created the Fisheries Department domiciled in the Ministry of Agriculture to spearhead fisheries development in Kenya. In 1960s, the Fisheries Department started to promote the nascent industry through "Eat More Fish Campaigns" and it helped to the rapid spread of aquaculture production in the of rural areas (Mbugua, 2008). Due to this initiative over 30,000 fish ponds were constructed by early 1970s in the Nyanza and Western Provinces (Zonneveld, 1983). However, in spite of the massive adoption of aquaculture pond farming, most of the ponds were later abandoned (Charo-Karisa & Gichuri, 2010). From the year 1970 to 2006, aquaculture production oscillated between 1,000 – 4,000 metric tons. According to Nyandat and Owiti (2013), in the year 2007, about 4,250 metric tons of fish were produced by 4,742 farmers countrywide from 7,477 ponds which covered 217 Ha, 301 dams and reservoirs 497 Ha as well as 248 tanks and raceways.

2.3.2 Aquaculture Production in Kenyan Economy

Aquaculture production plays an crucial role to the Kenyan economy by contributing to food security, income generation and poverty alleviation (Ngugi & Manyala, 2009; Rothuis *et al*., 2011; Ogello & Munguti, 2016). Between the years 2009 and 2013, the Government of Kenya on its agenda to revitalize the economy, they introduced and implemented a program called the Economic Stimulus Programme (ESP) under which aquaculture was recognized as a key pillar in the agriculture production sector (Ole-MoiYoi, 2017). A tremendous expansion in aquaculture was realized and it provided high-protein food, income and employment opportunities to the Kenyan people. The main focus of Economic Stimulus Programme was the construction of ponds, production of aquaculture diets, breeding and supplying of fingerlings as well as human resource capacity building for fish farmers and associated institutions (Musa *et al*., 2012). Kenya made a notable progress in promoting aquaculture production (Munguti *et al*., 2021). Aquaculture is also recognised as a way for solving food insecurity, employment and poverty reduction by Kenya's Vision 2030 and other legal, policy and institutional frameworks. In Kenya, aquaculture production rapidly rose from 4,218 tons in 2006 to 24,096 tons in 2014 (Munguti *et al*., 2021) as a result of the government's supportive policies together with investments from the public (Obiero *et al*., 2019), and this includes some parts of the country with very little history of aquaculture production and fish consumption (Ole-MoiYoi, 2017). From 2015, aquaculture production start to decline gradually, despite the rise in demand as well as per capita consumption of fish in the country as shown in figure 2.3 below. In the year 2017, aquaculture production was 12,356 tons, with only 0.014% part of Kenya being suitable for aquaculture (Munguti *et al*., 2021). As a result of population growth, income growth, increase in awareness of the potential health benefits obtained from fish (Ogello & Munguti, 2016; Obiero *et al*., 2019), continuous consumption of fish will come from either imports or aquaculture. In spite of the wild catch fisheries currently being regarded as the remaining principal fish supplier in Kenya, fish production through aquaculture is projected to take part in sustaining fish supply in order to meet the ever-increasing fish demand to year 2030. Thus, aquaculture farming is often considered an alternative to bridge the gap between fish demand and its supply in the country (Obiero *et al*., 2019).

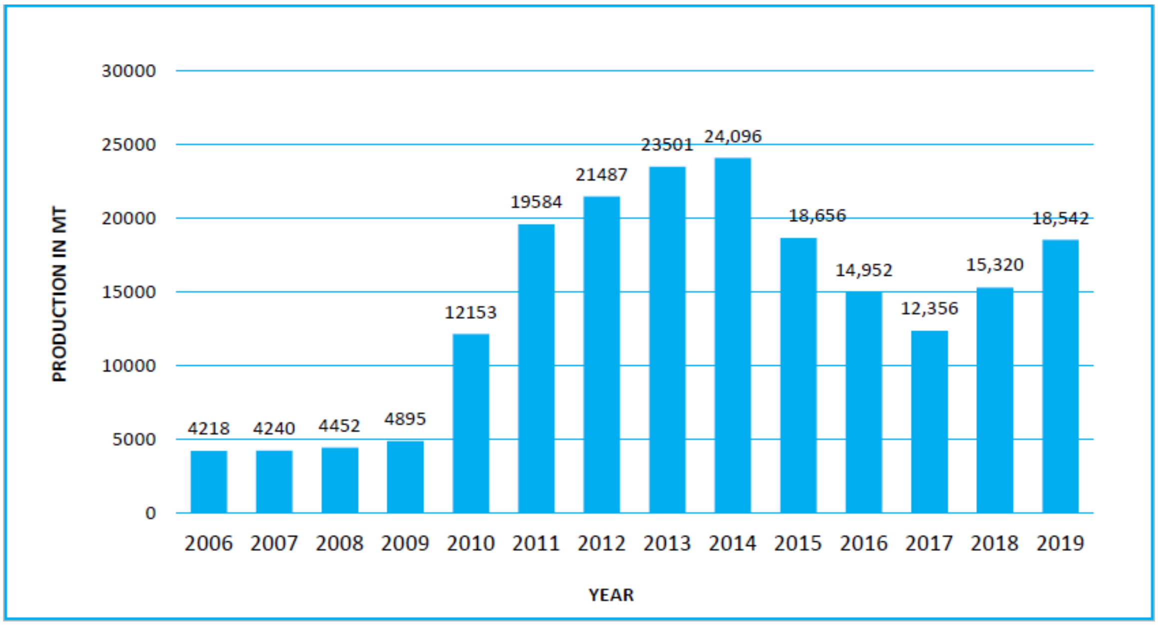

Figure 2.3: Aquaculture production in Kenya from 2006 – 2019. (Source: KNBS 2020)

2.3.3 Challenges and Opportunities in the Kenyan Aquaculture Sector

Currently, Kenya's aquaculture production sector is developing from traditional to modern aquaculture systems, but the sector has since never realized its full potential due to a number of constraints (Munguti *et al*., 2021). Some of the constraints include inadequate supportive infrastructure such as fish feed industries and fish hatcheries, inadequate fish fingerlings, inadequate high-quality and cheap fish feeds, (Munguti *et al*., 2021), slow adoption rate of aquaculture technologies, poor management of records which leads to wrong data from fish producers through the aquaculture value chain like labour, cost of inputs and volumes of fish harvested, poor security on fish in ponds and cages posed by predators and thieves, slow adoption rate of aquaculture technologies (GoK, 2016; Munguti *et al*., 2021). Additionally, the Kenyan aquaculture is at risk due to the weak and inadequate policies as well as legal frameworks on fish feeds and fingerlings to be certified in order to monitor compliance of quality production and supply of the fish seed (Amankwah *et al*., 2016).

2.3.4 Fish Species Cultured in Kenya

In Kenya farmers need to identify the fish they intend to culture, considering their environments and waters available, whether fresh or salt, warm or cold (Matanda *et al*., 2017). Adequate climatic diversity of warm fresh waters has enabled the cultivation of Nile tilapia (*O. niloticus*) and African catfish (*C. gariepinus*) which are the major species of fish being farmed in Kenya. Nile tilapia contributes 75% of cultured fish followed by catfish at 18%. These species are found in almost all aquatic systems in Kenya (Musa *et al*., 2012) and have high consumer preference locally and regionally. According Opiyo *et al*. (2018) Common carp (*C. carpio*) and Rainbow trout (*O. mykiss*) contributed 4% and 1% respectively and both the Rainbow trout and Common carp were introduced in Kenya during colonial era. Nile tilapia and African catfish can be reared in any freshwater culture system. However, Rainbow trout (*O. mykiss*) is limited to only cold areas at the slopes of Mount Kenya where water temperature do not rise above 19°C (Obiero *et al.*, 2014). The largemouth bass (*Micropterus salmoides* Lacepède, 1802) are also cultivated in the country (Matanda *et al*., 2017). Some ornamental fishes produced in small scale mostly for regional market include Koi carp (*Cyprinus rubrofuscus* Lacepede, 1803), Goldfish (*Carassius auratus* Linnaeus, 1758), and Sword tail (*Xiphophorus hellerii* Heckel 1848).

2.4 The African Catfish (*Clarias gariepinus* Burchell, 1822)

2.4.1 Systematics, Classification and Distribution of African Catfish

African catfish (*C. gariepinus*) is also known as sharptooth catfish, (Fig. 2.4) because their bands of teeth are fine and pointed (Skelton, 1993). It is a distinctive group of fish which belongs to the Subclass Actinopterygii, Division Teleostei, Order Siluriformes (Matanda *et al*., 2017) and Family Claridae consisting of 14 genera, 5 subgenera and 32 species which includes *Clarias Clarioides, Anguillo, Brevicephaloides and*

Platycephaloides (Idahor *et al*., 2018). It is native to Africa and the Middle East (Spataru *et al*., 1987) and it has a wide range of ubiquitous habitat demands (Matanda *et al*., 2017). This fish species is extensively distributed throughout the African continent thus from Niger and Nile river system to the Orange-Vaal region, the Cunene and Okavango river systems in Southern Africa as well as the lakes in the East African rift valley (De Moor and Bruton, 1988; Picker and Griffiths, 2011). Hecht and Uys (1988) also said they have been found in Eastern Europe as well as in the Middle East.

Figure 2.4: African catfish (*C. gariepinus*) (Source: Barasa, 2020)

2.4.2 Habitat Requirements of the African Catfish

African catfish can tolerate wide a range of environmental conditions. Also this fish can be found in almost all water bodies which includes vegetated swampy areas in the lakes, seasonal pools, rivers, lakes and floodplains which are likely to dry up during drought periods (Akinsanya & Otubanjo, 2006). According to Nelson. (2006), African catfish's wide distribution is attributed to its ability to utilise atmospheric air as well as its tolerance to low dissolved oxygen. According to Skelton. (1993) these fish also burrow in mud to enable themselves survive without water for some period.

2.4.3 Reproduction Biology of African Catfish

During breeding period the *C. gariepinus* laterally migrate from large water bodies where they feed and grow up to twelve months, to breed in the temporarily flood grassy marginal areas (Witte & Densen, 1995). This migration usually occurs shortly after the beginning of the rainy season (Gizaw, 2017) and is carried out in shoals (De Moor & Bruton, 1988). The predictive signals for maturation of gonads include the rise in water level, temperatures, photoperiod as well as electrical conductivity (De Graaf & Janssen, 1996; Ponzoni & Nguyen, 2008). The African catfish gonadal maturation has a seasonal cycle which is associated with the wet-dry seasons (Gizaw, 2017). Usually courtship, spawning as well as laying of eggs occurs during the night after the rains (Bruton, 1979). They usually lay their eggs on vegetation found in temporarily flooded areas (Skelton, 1993). Hatching of the eggs usually takes place between 24 to 36 hours after the eggs has been laid (Bruton, 1979) and there is no care for the newly hatched ones by their parents (Hecht & Uys, 1988).

2.4.4 Food and Feeding Behaviour of the African Catfish

Quite a lot of studies on African catfish's feeding habits have been documented (Willoughby & Tweddle, 1978; Tesfaye, 1998; Elias, 2009). These studies pointed out that in expanded niches, the African catfish can find variety of foods to consume. Despite the wide variety of food to consume, no uniform pattern with regard to the natural dietary composition of the African catfish has been established (Gizaw, 2017). This species of fish is considered to be both a predator and opportunistic omnivores (De Graaf & Janssen, 1996). They feed on different variety of animal and plant materials such as weeds, planktons, small insects, small fish crustaceans, worms, snails (Hecht & Uys, 1988) and they also eat rotting flesh (De Moor & Bruton, 1988). When there is scarcity in its prey, the African catfish can effectively change diets by consuming any available foods. This species of fish can also take almost anything that can fit into their mouth (Ponzoni & Nguyen 2008). They are nocturnal feeder on a wide variety of foods (Hossain *et al*. 1999).

2.4.5 Water Quality and the African Catfish

According to Boyd (1990) and Moses (1992), the physico-chemical as well as biological factors can affect the quality thereby compromising its suitability for production of aquatic species. Water physically supports fish and all their life functions such as swimming, feeding, digestion, excretion and breeding. Water quality must be optimal in terms of physical, biological and chemical qualities for maximum growth and productivity of the African catfish in aquaculture (Bhatnagar & Devi, 2013). Jhingran. (1985) pointed out that any change from the optimum water quality can affect survival, growth and productivity of the fish. Therefore, the quantity and quality of water can determine the success or failure of an aquaculture enterprise (Piper *et al.*, 1892).

2.4.5.1 Temperature

African catfish species is known for its ability to tolerate very harsh conditions (De Moor & Bruton, 1988; Skelton, 1993). For them to tolerate extremely harsh conditions the African catfish species usually possess physiological adaptations (Teugels, 1986). Temperature ranging from 25-32°C was reported by Afazal *et al*. (2007) to be optimum for the growth, survival and productivity of fish and other aquatic species found in the tropical regions. Another study by Adeniji and Ovie (1982) also mentioned that 25-31°C is the excellent temperature range for culture of *Clarias* species.

2.4.5.2 Dissolved Oxygen (DO)

African catfish can also tolerate and survive in water bodies with extremely low oxygen concentrations. They can stay outside water bodies and survive for a considerable period of time using their specialized organ called the supra-branchial organ provided this organ stays moist (Skelton, 1993). Even though the dissolved oxygen requirements for fish species vary, the general standards for the growth of warm-water fish species should be more than 5 mg L^{-1} and 6 mg L^{-1} for cold-water fishes. However, catfishes are capable of surviving in water bodies with very low dissolved oxygen concentration of about 4 mg L^{-1} through gulping atmospheric oxygen (Santhosh & Singh, 2007).

2.4.5.3 pH

The quality of water suitable for aquaculture is also determined by the water pH, an indicator that determines the success or failure of an aquaculture enterprise.
In order to run a successful aquaculture enterprise the pH should range between 6.5 and 9 (Bhatnagar & Devi, 2013). However, the African catfish species tolerate wide ranges of pH (Safriel & Bruton, 1984; Huisman & Richter, 1987; Agbabiaka, 2010). Quality water is characterized by limited metabolite levels, proper temperatures, optimum pH, adequate oxygen, and other environmental factors that can directly or indirectly impact on fish growth (Gizaw, 2017).

2.5 Nutrient Requirements of the African Catfish

Nutrition is the key component that should be put into consideration if one is to produce high quality fish products (Biketi *et al*., 2018). As a result of the expansion in aquaculture industry, there is a rise in demand for compounded fish feeds that can supply adequate nutrients to the fish for them to grow (Craig & Helfrich, 2007; GoK, 2015). The nutritional requirements of fish vary with species and they also differ because of different fish life stages. For the fish to support its body functions such as reproduction and growth, the fish diets should contain adequate nutrients (Tacon, 2000; Craig & Helfrich, 2007). Presently, not all the specific dietary requirements (vitamins, essential amino acids, minerals and essential fatty acids) of the *C. gariepinus* have been determined (Talamuk, 2016).

2.5.1 Protein and Amino Acids Requirements of the African Catfish

Proteins are the key essential nutrients in fish diets because they form the greater part of the fish biomass. They also help in synthesis of enzymes (Biketi *et al*., 2018). The dry weight muscle of fish is comprised of about 70 percent of the protein. Throughout the life of a fish there should be a continuous supply of proteins for growth and maintenance (Robison *et al*., 2006). The African catfish like other fish species and animals, require certain amino acids and nitrogen (Table 2.2) rather than overall levels of crude proteins for growth. In fish feed manufacturing, protein is the most expensive ingredient (El-Sayed, 2004; Agbo, 2008; Nguyen *et al*., 2009) and usually mixing different protein-based sources in diets is more economical (Robison *et al*., 2006). Optimum levels of dietary protein in fish feeds depends on the feed intake of fish, growth rate of fish, the quality of the protein, dietary carbohydrates and management practices (Nguyen *et al*., 2009)

Despite several studies that have been done on proteins and amino acids nutritional requirements for catfish, there is still a debate as to which dietary protein is the most cost-effective. Viveen *et al*. (1985) reported that the crude protein requirement for *C. gariepinus* should range from 30 to 35 percent in order for them to grow well. Hecht and Uys (1988) also pointed out that on a dry weight basis, the optimal dietary crude protein requirement for *C. gariepinus* should range from 40-50 percent. Catfish fries requires higher protein levels of 45-50 percent in diets which decrease to 35 percent when they become fingerlings (Robison *et al*., 2006). Like other fish species, the

African catfish require the same ten essential amino acids which are methionine, isoleucine, arginine, leucine, tryptophan, valine, histidine, threonine, phenylalanine and lysine. Fish cannot synthesize these essential amino acids and therefore, they have to be incorporated in their diets. Lack of essential amino acids in the diets compromises fish growth as well as the feed efficiency (Guillaume *et al*., 2001). Wilson (2003) pointed out that even though the quantitative essential amino acids of many fish species have been studied, there is still a paucity of information on essential amino requirements of the African catfish. Some of the values of amino acids that have been used in African catfish diets include lysine 57 g kg^{-1} protein (Fagbenro *et al*., 1998), tryptophan 11 g kg^{-1} protein (Fagbenro & Nwanna, 1999), arginine 45 g kg^{-1} protein (Fagbenro *et al*., 1999a) and methionine 32 g kg^{-1} protein (Fagbenro *et al*., 1999b).

Table 2.2: Amino acids requirements of juvenile Catfish

Amino acids	**Ideal amino acid profile expressed as a % of lysine**	**Requirement as % of dry diet**
Lysine	100	1.2
Arginine	84	1.0
Histidine	29	0.4
Isoleucine	51	0.6
Leucine	69	0.8
Methionine	45	0.6
Phenylalanine	98	1.2
Threonine	39	0.5
Tryptophan	10	0.12
Valine	59	0.71

(Source: National Research Council [NRC], 1993)

2.5.2 Lipids and Fatty Acids Requirements of the African Catfish

Lipids (fats and oils) do not supply fish with only essential fatty acids and energy, rather they also helps in absorption of the carotenoid pigments and vitamins (NRC, 1993; De Silva and Anderson, 1995; Guillaume *et al*., 2001; Webster & Lim, 2002). According to De Silva & Anderson (1995), the importance of lipids in aquafeeds include diet palatability improvement and it also helps in reducing dust in feeds during manufacturing, transportation as well as storage. The dietary lipids in aquafeeds must be in sufficient amounts if the fish is to save or spare its protein from being used up for energy instead of growth (Talamuk, 2016). African catfish fingerlings and grow out fish requires diets with 8 to 12 percent lipids (Uys, 1989). Too much lipids can reduce feed intake of fish which will then decrease the growth rate of fish. Also to much lipids increase fat deposition hence fish quality is compromised (Tucker & Hargreaves, 2004) and storage of processed products will also be compromised (Robison *et al*., 2006). Additionally, processing and manufacturing of high-lipid feeds tend to be difficult if one is to pellet them.

2.5.3 Carbohydrates Requirements of the African Catfish

Carbohydrates are considered as the major form of energy which is stored in plant seeds, roots as well as plant tubers. Milikin (1982) described carbohydrates as cheap source of energy that can be used in manufacturing of aquafeeds. Warm and freshwater fish species such as *C. gariepinus* use very high dietary carbohydrate levels compared to marine and cold-water species (Tucker & Hargreaves, 2004). Milikin (1982) reported that the highest level of carbohydrates included in aquafeeds, without compromising fish growth is determined by their feeding habits. Despite the fact that the African catfish does not require carbohydrates, their diets must contain a considerable amount of carbohydrates from grains and their byproducts. Robison *et al*. (2006) pointed out that an ideal catfish diet should contain 25% or more digestible carbohydrates and 3-6% carbohydrates generally representing crude fibre. Since the African catfish does not have the ability to effectively digest crude fiber therefore, it should be added in very low quantities.

2.5.4 Mineral Requirements of the African catfish

Like any other animals, catfish do require mineral nutrients for metabolism and development of bones (Robison *et al*., 2006). Guillaume *et al*. (2001) pointed out that it is difficult to study the minerals of fishes since they are able to get some from the surrounding waters. Usually minerals are classified into micro and macro minerals and they help in maintaining acid-base and osmotic balances as well as enzyme system activators (Webster & Lim, 2002). Surrounding waters can also help fish to acquire minerals like magnesium, potassium, calcium, zinc, selenium, sodium and (NRC, 1993). Nevertheless dietary phosphorus should be included in fish diets in form of dicalcium and defluorinated phosphates because feedstuffs from plant sources have very poor phosphorus and also natural water tend to have very low dissolved phosphorus (Webster & Lim, 2002).

2.5.5 Vitamin Requirements of the African catfish

Vitamins are required for growth, health and reproduction of fish and they should be supplied in minute quantities (Webster & Lim, 2002). According to Pillay and Kutty (2005) vitamins helps in maintaining the physiological functions as well as metabolic functions of the fish. According to Lucas and Southgate (2003) vitamins are classified into two groups which are namely water soluble vitamins and fat soluble vitamins. Water soluble vitamins includes (vitamin C, B group and other specific cofactors) while fat soluble vitamins include vitamin (A, D, E, K). Like any other fish species, the African catfish require all the 15 vitamins (Table 2.3). Fish vitamin requirements are determined by type of fish, size, environment and the other nutrients incorporated in the diet (Lovell, 1989). Diets with high vitamins can lead to vitaminosis (Lucas & Southgate, 2003). However diets with low vitamins can lead to poor growth, nutritional diseases and also the fish will become susceptible to infection (De Silva & Anderson, 1995).

Table 2.3: Vitamin requirements of Channel catfish (*Ictalurus punctatus*)

Vitamin	**Requirement (units/kg diet)**
Vitamin A	1000 – 2000 *IU*
Vitamin D	500 *IU*
Vitamin E	25 *IU*
Vitamin K	NR
Thiamin (vitamin B1)	1 *mg*
Riboflavin (vitamin B2)	9 *mg*
Pyridoxine Vitamin B6	3 *mg*
Pantothenic acid	10 *mg*
Niacin	14 *mg*
Biotin	R
Folic acid	1.2 *mg*
Vitamin B-12	R
Choline	400 *mg*
Ascorbic acid (vitamin C)	60 *mg*

(Source: NRC, 1993)
R - Required but no value determined
NR - No requirement determined

2.6 Feeds and Feed Ingredients used in Aquaculture Production

2.6.1 The Use of Fish Meal in Aquafeeds

Mostly fish meal is incorporated in diets of animals in order to improve the efficiency of the feeds and to promote growth of animals by enhancing feed palatability and nutrient digestibility (Miles & Chapman, 2006; Hodar *et al*., 2020). It is very important because of its protein quality thus it has a balanced amino acid composition good for formulating animal diets (FAO, 2001; Balios, 2003). According to Miles and Chapman (2006) the amino acid profile of fish is balanced and it helps in balancing other nutrients from either plants or animals when formulating diets providing a collaborative effect that improves growth rate of fishes in aquaculture.

Fishmeal as a feed stuff is considered high valued because it contains high levels of digestible essential amino acids, fatty acids and phospholipids which are often absent in plant-based protein sources (FAO, 2001; Balios, 2003). Additionally, fish meal has very low fibre contents and they also contains major elements (phosphorous, calcium, potassium and magnesium), trace elements (manganese, cobalt, copper, iron, iodine, selenium, fluorine, and zinc) apart from its vitamins (B1, B2, B6 and B12) (FAO, 2001). Also, fishmeal do not contain anti-nutritional factors (ANFs) making it more beneficial compared to plant-based protein sources. Typically, aquafeeds contain higher percentages of fishmeal than other animal feeds and the level of fishmeal in a particular diet depends on whether the fish species is an omnivore or carnivore.

2.6.2 The Use of Plant Protein Feed Resources in Aquafeeds

Feed ingredients that originate from plants have a huge potential for being widely used in feed industries because of their affordable cost compared to animal-based protein sources. Major plant-based protein sources used in formulation of aquaculture diets include cereals and oilseeds (Tacon *et al*., 2011; Oliva-Teles *et al*., 2015). Tilapia, carp and catfish have been successfully fed with plant-based diets and the results showed a significant improvement in terms of growth performance (Tacon & Metian, 2009). Agbo. (2008) suggested that legume seeds and oilseed cakes must be utilized as an alternative source of protein for aquaculture feeds. Okoye and Sule (2001) pointed out that in order to promote fish production, continuous studies must be done for both the locally available conventional and non-conventional plant sources. However, in the past decades information contradicting the utilization of plant protein-based ingredients has risen. In spite of the low cost and availability of most plant ingredients, their utilization in aquaculture feed industry is limited due to low protein content, unbalanced amino acid profile, too much starch and fibre contents as well as availability of anti-nutritional factors (NRC, 1993).

2.6.3 The Use of Insects in Aquafeeds

According to Fiaboe and Nakimbugwe (2014), since fish and other animals are known to ingest insects in their natural environment, this suggests that fish may have undergone evolutionary changes that allow them to incorporate insects into their standard diet. Insects have been proposed for a long time as an alternative protein source for aquaculture diets and a number of studies have been conducted to see the possibility of using insect meal as a substitute for fish meal at different levels. The major insects that were used in these studies are black soldier fly (Bondari & Sheppard, 1987; Rana *et al*., 2015; Xiao *et al*., 2018; Limbu *et al*., 2022), common housefly (Ogunji *et al*., 2008; Obeng *et al*., 2015), silkworm (Kurbanov *et al*., 2015; Karthick *et al*., 2019) and grasshopper (Alegbeleye *et al*., 2012; Olaleye, 2015). Several studies on the use of BSFL to feed different species of fish have been documented. For example after giving diets that contains BSFL, there were no negative effects seen on the growth performance of fish (Li *et al*., 2017; Zhou *et al*., 2018). In another study, fishmeal was replaced with silkworm pupa meal in the diets of African catfish fingerlings at varying inclusion levels and the study concluded that the silkworm pupa meal could be used up to 50% without having any negative impact on the growth of the fish (Kurbanov *et al*., 2015). Different inclusion rates of variegated grasshopper (*Zonocerus veriegatus* Linnaeus 1758) meal have been be utilized in the diets of African catfish fingerlings in place of fishmeal. According to the findings of a study conducted by Alegbeleye *et al*. (2012), variegated grasshopper can successfully substitute fishmeal in diets of African catfish fingerlings up to 25% without having any negative impact on growth, weight increase, or feed conversion ratio.

2.7 The Black Soldier Fly (*Hermatia. illucens* Linnaeus, 1758)

Figure 2.5: Adult Black Soldier Fly (*Hermatia illucens*) (Source: Author 2022)

2.7.1 Scientific Classification of Black Soldier Fly

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Diptera
Sub-order:	Brachycera
Infra-order:	Tabanomorpha
Super-family:	Stratiomyidea
Family:	Stratiomyidae
Genus:	Hermetia
Species:	*Hermatia illucens*
Binomial Name:	*Hermatia illucens*; Linneaus, 1758. (Source: Rana *et al*., 2015)

The Black soldier fly (BSF) (*H. Illucens*) is an insect species native to Kenya. They are often found in and near heaps of faecal waste from swine, poultry as well as from other livestock including goats, sheep and cattle (Chia *et al*., 2018). BSFL can also be cultured on various types of organic wastes (Liland *et al*., 2017). According to Li *et al*. (2011), the development/life cycle of BSF comprises of four stages which include the egg, larvae, pupae and the adult fly as shown in figure 2.6 below.

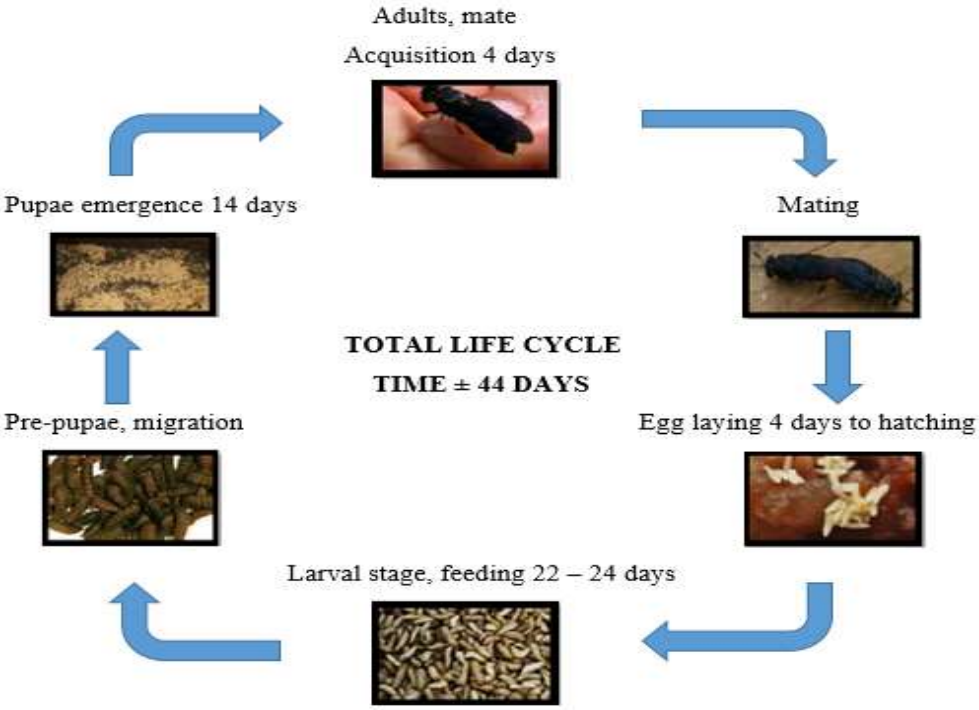

Figure 2.6: Life cycle of the Black soldier fly (Source: Alvarez, 2012)

Due to the fact that BSFL larvae migrate to a certain pupation zone, they have an inbuilt adaption that allows them to self-harvest during domesticated production (Sheppard *et al*., 1994). Adult BSF are typically not attracted to people and their habitats. Since they do not feed or lay their eggs near food sources, they are not considered to be disease vectors. They also don't contaminate human food or water, therefore they do not pose any threat to human health (Banks *et al*., 2014). BSF larvae are easily identifiable by their dull whitish to brownish blackish colour and they feed on refusals and sieves can be used to harvest them manually.

Due to their close relationship with faecal waste, the black soldier fly larvae are also known as loo maggots (Myers *et al*., 2008). It is also possible to find these maggots in industry zones, such as trash pits at beer manufacturing facilities and refuse pits at processing plants, such as those that deal with vegetables, coffee as well as fish processing plant waste zones (Banks *et al*., 2014). The larvae of the black soldier fly can be processed into a variety of feeds for livestock, including those for cattle, swine, and several poultry species, in addition to those for aquaculture species (Wang and Shelomi, 2017). The BSFL crude lipids have the potential to possibly be utilised as a source of biofuels (Leong *et al*., 2016). Li *et al*. (2011) pointed out that one thousand larvae had the potential to produce between 36 and 91 grams of biofuel, depending on the kind of substrate in which they are reared. Black soldier fly larvae oils have been tested for suitability in making skin care products (Sangduan, 2017). Mass production of BSF larvae for making livestock feeds in animal feed industry is not difficult and has the advantage of enhancing the bioconversion as a commercial venture (Bava *et al*., 2019).

2.7.2 Nutritional Compositions of Black Soldier Fly Larvae

The utilisation of BSF larvae meal by animals including fish is determined by its nutritional profile (Ogunji *et al*., 2008). Literature have reported different nutritional values of BSFL and these were due to its age and the methods of drying (Aniebo & Owen, 2010), method of processing (Fasakin *et al*., 2003), species variation as well as harvesting time (Atteh and Ologbenla, 1993). Table 2.4 shows the nutritional composition of BSFL. The amount of protein found in larvae of black soldier flies that were fed on cow and swine dung is comparable at 42% and 43%, respectively. Despite the substrate used to feed the BSFL, the amount of protein contained in the larvae (Table 2.4) is sufficient to fulfil the protein requirements for *Clarias*.

Table 2.4: Nutritional composition (% dry matter) of BSFL reared on cattle and swine manure

Parameter (%)	BSFL reared on cow manure	BSFL reared on swine manure
Crude protein	42.1	43.6
Crude fat	34.8	33.1
Crude fibre	7	Not defined
Ash	14.6	15.5

(Source: Haasbroek 2016)

2.7.2.1 Protein and Amino Acids

Due to the fact that BSFL contains adequate proportion of all essential amino acids, they are suitable for use as a food source in fish diets. The BSF larvae that were raised on cow and swine manure providing essential amino acids (Haasbroek, 2016) are shown in Table 2.5 below. Some of the specific amino acid requirements were not identified. Usually, the amino acid levels determined for Channel catfish (*I. punctatus*) are also used for African catfish formulations. In most cases, the amino acid values that have been identified for Channel catfish (*I. punctatus*) are likewise employed for formulations of African catfish diets. The amino acid profiles of BSFL and the amino acid requirements for African catfish are compared in Table 2.5. According to Pantazis (2005), BSFL lack some of the amino acids such as threonine, methionine and tryptophan. Despite this, amino acids can be used to balance those in BSFL when mixed with other components of the diet. Compared with values in Table 2.5 when BSFL are reared for production of oil and protein meal, Newton *et al*. (2005) proposed an increase by 40% in amino acid levels. Removing the cuticle improves the profile of BSFL amino acid (Newton *et al*., 2005).

Table 2.5: Amino acid composition (mg g^{-1} dry matter) of BSFL reared on different substrates against *C. gariepinus* requirements

Amino Acids	**BSFL reared on cattle manure**	**BSFL reared on pig manure**	**African catfish amino acid requirements**
Valine	101	101	46
Phenylalanine	65	67	102
Tryptophan	6	27	58
Methionine	26	38	71
Threonine	16	64	45
Isoleucine	58	68	35
Leucine	104	118	108
Arginine	67	81	Not defined
Histidine	58	42	32
Lysine	100	100	100

(Source: Haasbroek 2016)

2.7.2.2 Mineral Content

According to Fasakin *et al*. (2003), the nutritional contents of black soldier fly larvae, including the mineral content, are affected by a variety of factors, including the procedures used to treat and dry the larvae, as well as the age at which they were harvested. Additionally, the variations in the substrates used to rear the black soldier fly larvae have an effect on the mineral compositions of the larvae (Newton *et al*., 2005). The phosphorus content was higher in BSFL grown on poultry manure compared to swine manure, while calcium content was high in BSFL reared on pig manure and were found to have rich macro-minerals such as phosphorus which exceeded the African catfish requirements for minerals.

Table 2.6: Mineral composition (% dry matter) of BSFL reared on pig and poultry manure

Mineral	BSFL reared pig manure	BSFL reared poultry manure
Calcium (%)	5.36	5.00
Potassium (%)	1.16	0.69
Magnesium (%)	0.44	0.39
Phosphorus (%)	0.88	1.51
Iron (ppm)	766	1370
Manganese (ppm)	348	246
Zinc (ppm)	271	108

(Source: Newton *et al*., 2005)
ppm = parts per million.

2.7.2.3 Lipids and Fatty Acids

The total lipid content of black soldier fly greatly surpasses the African catfish requirements, which typically ranges between 8 and 10 percent. However, BSFL essential fatty acids can change due to the substrate that was used in rearing the larvae. Several studies have confirmed that black soldier fly larvae have fatty acids that are much considered important in aquafeeds (Sealey *et al*., 2011; Kroeckel *et al*., 2012) These fatty acids include the polyunsaturated fatty acids (PUFA), monounsaturated fatty acids (MUFA) and saturated fatty acids (SFA) (Barroso *et al*., 2014; Surendra *et al*., 2016). Some studies on black soldier fly larvae showed negligible levels of highly unsaturated fatty acids.

2.7.3 The Uses of Black Soldier Fly Meal in Aquaculture

A number of studies have been done on inclusion of BSFL meal in aquaculture feeds. The researchers reported that BSFL can be incorporated to partially or fully replace fish meal in feeds of different fish species (St-Hilaire *et al*., 2007; Sealey *et al*., 2011; Sanchez-Muros *et al*., 2014; Rana *et al*., 2015; Talamuk, 2016; Lock *et al*., 2016; Katya *et al*., 2017; Li *et al*., 2017; Xiao *et al*., 2018; Zhou *et al*., 2018; Wang *et al*., 2019; Caimi *et al*., 2020; Mapanao *et al*., 2021; Limbu *et al*., 2022). From previous studies there is a paucity of information regarding the evaluation of black soldier fly larvae as a feed ingredient for African catfish diets. Although it has been reported that African catfish may survive in harsh environments, the species is more commonly associated with freshwater environments and can be found in landlocked African nations (Talamuk, 2016).

2.8 Effects of Diets on Fish Carcass Proximate Composition

Fish nutrition is an important aspect in aquaculture industry and it influences the quality of fish meat. The quality and quantity of fish feeds affects the body nutrient retention as well as the carcass composition of the fish (Baltić *et al*., 2011; Noor *et al*., 2011). Quality together with quantity of fish feeds determines the body nutrient retention and influences the carcass quality of the fish. According to Khalid *et al*. (2014), nutrient retention in the body depends on the quantity and quality of fish diets thus influencing carcass composition. The nutrients contained in fish diets are broken down into simple nutrients through digestion and are absorbed and utilised for different functions in the body or assimilated in the body which then as a result influence the meat composition (Biketi *et al*., 2018). Fish diets influence nutrient levels such as protein, fat content, vitamins, glycogen, and minerals for which these have an impact on organoleptic properties of the fish carcass which include flavour, texture colour, appearance as well as the shelf life of fish and fish products (Rasmussen, 2001; Baltić *et al*., 2011). The major objective in aquaculture production is to formulate and produce low-cost fish feeds to widen the profit margin and ensure the industry's sustainability. However, replacement of fishmeal as a major protein ingredient with low-cost feed ingredients should be assessed not for growth performance only but for meat quality as well.

2.9 Conclusion

It is quite remarkable that in spite of the above-mentioned past research, the aquaculture feed industry still has some challenges. One of the major challenges is the demand for production of high-quality feeds in order to satisfy customers in a cost-effective way. Without the benefit of alternative and cost-effective protein sources to formulate fish diets, this industry will face some difficulties. This research work aimed at evaluating BSFL meal a potential ingredient to replace fishmeal in African catfish rearing.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The study was carried out under greenhouse conditions at Jaramogi Oginga Odinga University of Science and Technology (JOOUST), Fish Farm. The University is located in Bondo Town, Siaya County in the western part of Kenya, approximately 62 kilometres, by road, west of Kisumu City. The geographical coordinates of the university are 0°05’38.0”S, 34°15’31.0”E (Latitude:-0.093889; Longitude:34.258611) The area experiences temperature ranges of 15-30°C, 57-87% relative humidity (RH), 800-2,000 mm annual rainfall and 70% atmospheric pressure (Achonga *et al*., 2011).

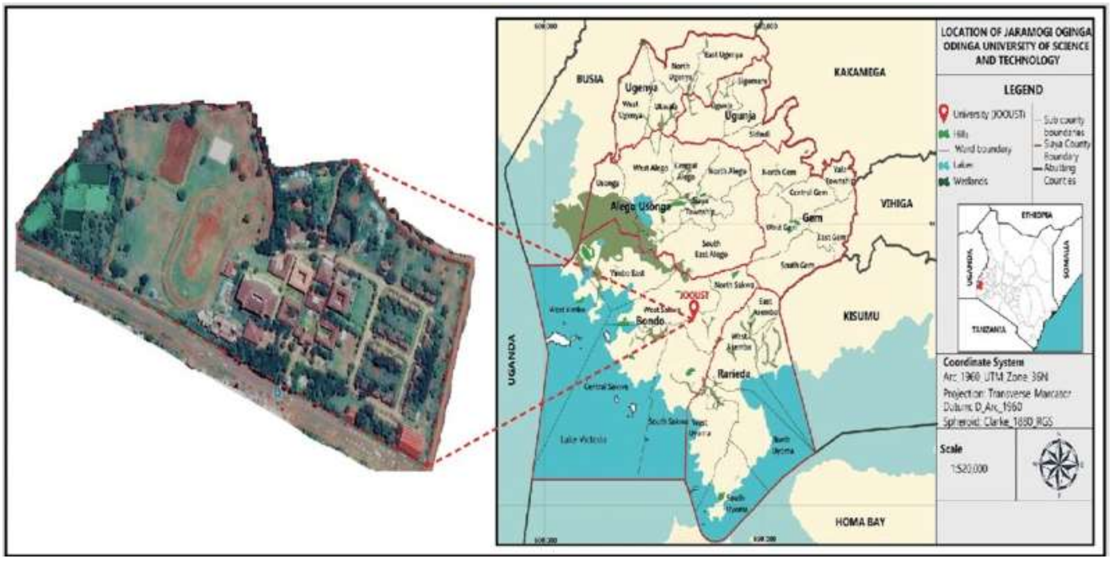

Figure 3.1: Location of Jaramogi Oginga Odinga University of Science and Technology

3.2 Sourcing of Feed Ingredients

Black soldier fly larvae were obtained from Jaramogi Oginga Odinga University of Science and Technology Insectary. The BSFL was stored in bags at room temperature until time of use. The other feed ingredients (fish meal, cassava, rice bran) were sourced from local markets. Ingredients selection was based on local availability in sufficient quantities, cost, need for disposal as well as the nutrient profile of the ingredient (Nyakeri, 2018). Preference was given to those ingredients which are by-products or waste products, whose incorporation in feeds could also enhance best practices in natural resource use and waste management (Madu *et al*., 2003). Mineral premixes and vitamins were commercially sourced and they were incorporated into the diets in the recommended proportions in order for the diets to meet the National Research Council (NRC) recommended amounts for African catfish (NRC, 1993).

3.3 Analysis of Feed Ingredients

Samples of the black soldier fly larvae meal (BSFL), fish meal (*Rastrineobola argentea*), cassava and rice bran were taken for laboratory analysis at the Department of Animal Production, University of Nairobi before formulation of experimental diets. These ingredients were analysed for ash content, moisture content, crude fat content, crude fibre content and crude protein content using the (Association of Official Analytical Chemists, [AOAC] 1998) guidelines. Triplicate measurements were recorded for each feed sample. All the feed samples were dried at 105°C for determination of moisture content. A combustion method at 550°C using a muffle furnace was used to determine the ash content of the samples. Crude protein was determined by nitrogen analysis (N x 6.25) using the Kjeldahl method. The Soxhlet extraction method using petroleum ether (40–60°C, boiling point) was used to determine ether extract content of the samples. Crude fibre content was obtained by digesting the dry lipid-free residues with 1.25% Sulphuric acid, 1.25% Sodium hydroxide and calcined. The nitrogen free extracts (carbohydrates) were determined as 100 – (ash + crude fat + crude protein + moisture content + fibre). The proximate compositions (% as-fed) of the ingredients that were used to formulate experimental diets for the study are shown in Table 3.1 below.

Table 3.1: Proximate compositions (% as-fed) of the ingredients used to formulate experimental diets for the study

	Ingredients			
Parameter (%)	**BSFL**	**Fish meal**	**Cassava**	**Rice bran**
Dry matter	92.54	89.14	95.62	89.02
Ash	16.90	16.83	5.24	10.02
Ether extracts	18.08	11.70	7.23	12.04
Crude protein	46.41	65.12	12.51	8.11
Crude fibre	16.96	2.08	6.52	18.81
Nitrogen free extracts	1.65	4.28	68.50	51.02

3.4 Feed Formulation and Manufacturing

Feed manufacturing was done at a local feed company called Great Lake Feeds located on the shores of Lake Victoria in Usenge, Siaya County, Kenya. The main goal of formulating diets was to obtain nutritionally balanced diets which can help in growth and maintenance of the fish at affordable costs (NRC, 1993). After the laboratory analysis of feed ingredients, five iso-nitrogenous and iso-lipid experimental feeds were formulated targeting the African catfish feeding standards (NRC, 1993; Munguti *et al*., 2014), containing, 40% protein and 8% fat as shown in Table 3.3. The experimental feeds were formulated to partially or completely replace fishmeal with BSFL meal. The experimental diets were supplemented with BSFL meal at inclusion levels of 0% (control diet), 25%, 50%, 75% and 100%. The inclusion levels of all ingredients that were used to formulate feeds were calculated using the WinFeed Least Cost Feed Formulation Software Version 2.8 (WinFeed (UK) Limited) to obtain feeds whose compositions are shown in Table 3.2 below.

Table 3.2: Contribution of the major ingredients used in the formulation of the experimental diets of *C. gariepinus* fingerlings

Feed ingredient	**Formulated dietary treatments (fish meal substitution with black soldier fly larvae %)**				
	BSFL 0%	**BSFL 25%**	**BSFL 50%**	**BSFL 75%**	**BSFL 100%**
Fish meal	50.44	37.83	25.22	12.61	0.00
BSFL meal	0.00	20.15	40.30	60.45	80.60
Rice bran	18.72	15.76	12.79	9.82	6.85
Cassava flour	28.84	24.26	19.69	15.12	10.55
Vit-min premix	2.00	2.00	2.00	2.00	2.00
Total (Kg)	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

A semi-commercial stainless steel feed mixer Model M20A KITMA China, at 100 rpm operated at 220-240 Volts was used for feed mixing. All the ingredients were mixed thoroughly for three minutes to get a homogenous mixture. A 25% clean water mixture with vitamin-mineral premix was added into the feed, and proceeded with mixing for another three minutes to form a dough. The dough was pressed through a manual wet mincing machine at high pressure to produce 2 mm pellets. The pellets were dried in the sun for one day and later on packed in labelled airtight bags to prevent absorption of moisture and growth of moulds. The pellets were finally crushed to approximately 0.5 mm to facilitate ingestion by the fingerlings.

3.5 Laboratory Analysis of Feeds

After the feeds were manufactured, samples of all the treatment diets were taken for proximate analysis at Department of Animal Production, University of Nairobi. The proximate analysis was carried out according to the standard methods by Association of Official Analytical Chemists [AOAC] (1998) as described in section 3.3. The proximate composition (%) of the experimental diets used in the study are show in Table 3.3 below.

Table 3.3: Proximate composition (%) of the experimental diets used in the study

	Experimental diets				
Parameter	**BSFL 0%**	**BSFL 25%**	**BSFL 50%**	**BSFL 75%**	**BSFL 100%**
Dry matter	91.68	91.73	92.13	92.24	92.61
Ash	15.30	16.16	14.21	13.40	12.27
Ether extract	8.36	8.15	8.39	8.26	8.37
Crude protein	39.72	40.34	40.17	39.75	40.39
Crude fibre	6.32	6.98	7.30	8.33	8.31
Nitrogen free extracts	30.31	28.37	29.94	30.26	30.67

3.6 Acquisition of African Catfish Fingerlings

The *C. gariepinus* was chosen in this study since it is capable of rapid reproduction and can consume a diverse array of food, including insects and they can survive in environments with low concentrations of dissolved oxygen. Six hundred mixed sex *C. gariepinus* fingerlings (mean weight 0.47±0.02 g) used in this experiment were procured from the Tigoi Fish Farm located in Vihiga County, Western Kenya. The Catfish fingerlings were transported to the study site (JOOUST Fish Farm) in well-oxygenated polythene bags. The African catfish fingerlings were acclimatised for fourteen days before the commencement of the experiment.

3.7 Experimental Design

The five experimental diets were formulated and fed to the five groups of fingerlings in a Randomised Complete Block Design (RCBD). Each of the five treatments was replicated three times. A total of fifteen circular plastic tanks, each with a capacity to hold 250 L of water were used in the study. Forty Catfish fingerlings were randomly sampled and each batch placed in the plastic tank filled to 200 L resulting in a stocking density of 2 fingerlings per 10 L.

3.8 Fish Feeding and Management

The five experimental diets were randomly assigned to each plastic tank in triplicates. The fingerlings were fed at 6 percent body weight twice a day between 08:00 – 09:00 and 16:00 – 17:00 hours for twelve weeks. From the beginning of the feeding trial to completion at 84 days, 10 fingerlings per replicate were randomly sampled and weighed every two weeks and the amount of fish feed was adjusted according to fish body weight.

3.9 Water Quality Management

Water quality was also considered throughout the trial and water in each experimental unit tank was maintained to be within the critical limits acceptable for growth and health of catfish fingerlings (Ogunji & Awoke, 2017). Dissolved oxygen (DO), pH and temperature, were monitored on daily basis. Ammonia and nitrite were also measured once in fortnight. Fresh dechlorinated water was used to fill all circular plastic tanks throughout the study up to 80% of the total tank volume to avoid fish jumping out. During the study, 75% of water was replaced by siphoning out the water up to 25% of the total size of the tank by volume and replenishing with fresh dechlorinated water every two weeks to maintain water quality at optimum for catfish growth. Temperature and dissolved oxygen were measured using a multi-parameter water quality meter (YSI 550A). A portable waterproof pH meter was used to measure water pH.

3.10 Ethical Consideration

The experimental procedure was approved by Jaramogi Oginga Odinga University of Science and Technology Ethics Committee. Fish were handled with maximum care to limit the risks of unnecessary stress and mortality that may result from improper handling. (Society, 2004; Bennett *et al*., 2016; Sloman *et al*., 2019; Gili, 2021).

3.11 Data Collection

Before stocking the fingerlings in each tank, they were weighed using an electronic weighing balance (Scout Pro Balance, Ohaus) and measured for length using a measuring board through standardized meter ruler (cm) to determine their mean initial weight (g) and mean initial length (cm) respectively. Data on fish growth characteristics was recorded once every two weeks. During data collection, a sample of ten fish were randomly scooped from the plastic drums and put in buckets filled with water in order to reduce stress and deaths. Mortality was checked on daily basis and recorded.

3.11.1 Determination of Growth Performance

Growth performance, feed utilisation, condition factor and length-weight relationship of fish fed different percentages of BSFL meal protein replacement were determined for Mean Weight Gain (%) (MWG) (Opiyo *et al*., 2017; Iskandrar *et al*., 2017; Mapanao *et al*., 2021), Specific Growth Rate (SGR) (Zainal *et al*., 2016; Otieno *et al*., 2021; Limbu *et al*., 2022), Feed Intake (FI) (Teye-Gaga, 2017), Feed Conversion Ratio (FCR) (Agbo, 2008; Marissa, 2021; Baßmann *et al*., 2023), Protein Intake (PI) (Adegbesan *et al*., 2018), Protein Efficiency Ratio (PER) (Talamuk, 2016; Zainal *et al*., 2016; Iskandrar *et al*., 2017), Length-Weight Relationship (LWR) (Le Cren 1951; Ighwela *et al*., 2011) and Relative Condition Factor (K_n) (Anani & Nunoo 2016) using the following formulae, 1 to 9 respectively:

$$\text{Mean weight gain (\%)} = \frac{\text{Final body weight (g)} - \text{Initial body weight (g)}}{\text{Initial body weight (g)}} \text{x}100$$

Equation 1

$$\text{Specific growth rate} = \frac{\text{Ln final body weight} - \text{Ln initial body weight}}{\text{Number of feeding days}} \text{ x } 100$$

Equation 2

$$\text{Feed intake} = \frac{\text{Total feed intake per fish (g)}}{\text{Total number of days for the experiment}} \text{x}100$$

Equation 3

$$\text{Feed conversion ratio} = \frac{\text{Weight of feed fed (g)}}{\text{Weight gain of fish (g)}}$$

Equation 4

$$\text{Protein intake} = \frac{\text{Total feed consumed x Crude protein feed}}{100}$$

Equation 5

$$\text{Protein efficiency ratio} = \frac{\text{Weight gain of fish (g)}}{\text{Protein intake (g)}}$$

Equation 6

3.11.2 Length – Weight Relationship (LWR)

The total length (cm) of fish was determined using a measuring board whereas fish weight was determined by the Scout Pro Balance, Ohaus. The equation below was used to estimate the LWR:

$$W = aL^b$$

Equation 7

Where; W = Fish weight (g); L = Total fish length (cm); a = Exponent describing rate of change of weight with length (= the intercept of the regression line on the Y axis) and b = Regression line slope

The equation was log transformed for estimating the parameters 'a' and 'b'. When b = 3 isometric pattern of growth occurs but when b is not equal to 3, allometric pattern of growth occurs, which may be positive if >3 or negative <3. The log transformed data gave a regression equation:

$$\text{Log } w = \log a + b \log L$$

Equation 8

Where; a = Constant and b = The regression co-efficient

$$\text{Relative condition factor } (K_n) = \frac{W_o}{a \times L^b} = \frac{W_o}{W_p}$$

Equation 9

Where; W_o = Weight of fish observed in grams; W_p = Fish weight predicted from the equation $W = aL^b$; L = Total fish length in centimetres; and b = The exponent value obtained from the length-weight equation formula and a = constant in the length-weight relationship.

3.11.3 Determination of Carcass Composition

At the termination of the feeding experiment at day 84, ten fish per treatment were randomly picked for proximate analysis at the Department of Animal Production, University of Nairobi. The proximate analysis was carried out according to the standard methods by Association of Official Analytical Chemists [AOAC] (1998) as described in section 3.3.

3.11.4 Economic Analysis

The economic analysis was conducted to assess the cost-effectiveness and feasibility of using BSFL as a replacement for fishmeal in African catfish (*C. gariepinus*) feeds. Only feed cost was used in the calculation assuming that all other operating costs did not change. The cost of the diets was calculated using the prevailing market prices which were recorded during the time of the experiment as show in Table 3.4. The value of the fish was calculated using the sale price of KES 300.00.kg^{-1} fish (Source: Author 2022). The incident of cost and profit index (Agbo, 2008) were calculated using the following formulas;

$$\text{Incident of cost} = \frac{\text{Cost of feed (KES)}}{\text{Weight of fish produced (kg)}}$$

Equation 10

$$\text{Profit index} = \frac{\text{Value of fish produced (KES)}}{\text{Cost of feeding (KES)}}$$

Equation 11

Table 3.4: Cost of feed ingredients (KES) used in formulating experimental diets

Feed ingredient	**Price per Kilogram (KES)**
Fish meal (*Rastrineobola argentae*)	250.00
Black solider fly larvae	150.00
Cassava meal	30.00
Rice bran	20.00
Vitamin-mineral premix	250.00

(Source: Author 2022)

3.12 Statistical Analyses

Data obtained from each experimental diet consisting of random variables was tested using one-way ANOVA to test the significant difference for Mean Initial Weight (MIW) (g), Mean Final Weight (MFW) (g), Mean Initial Length (MIL) (cm) and Mean Final Length (MFL) (cm), water quality parameters, carcass composition parameters and economic performance parameters. Mean separation between treatments was determined by Post hoc test at $\alpha = 0.05$ and results for ANOVA were expressed as mean ± standard error (SE), while medians and average ranks for relative condition factors were separated using Kruskal-Wallis test. Other growth performance indices such as Mean Weight Gain (MWG) (%), Specific Growth Rate (SGR) (%), Feed Intake (FI) (g), Feed Conversion Ratio, Protein Intake (PI) and Protein Efficiency Ratio (PER) were not tested statistically because they did not meet the requirements for parametric analysis (they had single outputs/values). Growth in length and weight were analysed by comparing their increase against time (growth rate) to provide an objective way for comparing the slopes for the different treatments using and finally applying a General Linear Model (GLM) with treatment categorical variable. Mortality rate was analysed using arbitrarily censored failure times. A normal probability distribution was adopted after testing for normality by the Anderson-Darling test. The analysis provided estimates of percentiles and survival probabilities. Probability plots for each treatment was used to visualize the First Quartile, Third Quartile and Second Quartile Time to Failure and the expected percentages. All analyses were conducted using Minitab Ver 17.0 and Statgraphics Ver 16. The general linear model for randomized complete block design (RCBD) was;

$$\mathbf{Y_{ijk} = \mu + \alpha_i + \beta_j + e_{ijk}}$$

Equation 12

Where;

Y_{ijk} = is the k^{th} observation from i^{th} treatment in the j^{th} block,

μ = is the overall mean common to all observations,

α_i = is the effect of i^{th} treatment,

β_j = is the effect of the j^{th} block, and

e_{ijk} = random error, with a mean of 0 and a variance

CHAPTER FOUR

RESULTS

4.1 Growth Performance of African Catfish fed BSFL Based Diets

Results for growth performance of *C. gariepinus* of each treatment are shown in Table 4.1. Results indicated that the MFW and MFL of 25% was significantly higher than all the other treatments ($F_{0.05,\ 4}$=33.87, p-value = 0.001) and ($F_{0.05,\ 4}$=52.58, p-value = 0.001) respectively. The values of MWG (2789), SGR (4.00), FI (10.77), PI (4.31) and K_n (1.0049) for BSFL 25% gave better performance than the other treatments. The values of FCR (0.72) and PER (3.48) for BSFL 0% gave better results than other treatments.

4.1.1 Fish Growth Regression Slopes in Weights

A graphical plot of Log W against Time (days) for each treatment is shown in Figure 4.1. The Generalised Linear Model (GLM) of growth in weight with the diets as categorical treatments showed that there was adequate evidence that at least one of the slopes was significantly different. Multiple comparison using Fisher's Least Significant Difference (LSD) identified 4 homogenous groups. A visual examination of the plot showed that BSFL 25% was the best performing formulation, while BSFL 100% showed the poorest performance with an average growth rate of 0.7% per day as compared to BSFL 25% with a 1.27% growth rate per day.

Table 4.1: Growth performance, feed utilisation and condition factor of African catfish (*C. gariepinus*) fingerlings fed black soldier fly larvae-based diets for twelve weeks

Parameter	**Dietary treatments**						
	BSFL 0%	**BSFL 25%**	**BSFL 50%**	**BSFL 75%**	**BSFL 100%**	**F-Statistic**	**P-Value**
ANOVA (μ±SE)							
MIW (g)	0.48 ± 0.01^{a}	0.47 ± 0.02^{a}	0.48 ± 0.01^{a}	0.47 ± 0.02^{a}	0.47 ± 0.02^{a}	0.09	0.985
MFW (g)	11.89 ± 0.46^{b}	14.37 ± 0.69^{a}	10.14 ± 0.60^{b}	7.99 ± 0.58^{c}	6.27 ± 0.35^{c}	33.87	<0.001*
MIL (cm)	4.04 ± 0.08^{a}	4.05 ± 0.07^{a}	4.07 ± 0.08^{a}	4.04 ± 0.08^{a}	4.07 ± 0.08^{a}	0.03	0.998
MFL (cm)	11.96 ± 0.16^{ab}	12.73 ± 0.20^{a}	11.34 ± 0.22^{b}	10.22 ± 0.32^{c}	8.22 ± 0.28^{d}	52.58	<0.001*
Kruskal-Wallis (median(rank))						**H-Statistic**	**P-Value**
MWG (%)	2775	2789	2019	1674	1231		
SGR (%)	4.00	4.00	3.64	3.42	3.08		
FI (g)	9.51	10.77	8.43	6.07	4.17		
FCR	0.83	0.78	0.87	0.81	0.72		
PI	3.81	4.31	3.37	2.43	1.67		
PER	3.02	3.22	2.86	3.11	3.48		
K_n	1.0017 (540.7)	1.0049 (575.9)	0.9962 (540.9)	0.9942 (532.1)	0.9466 (437.9)	24.51	<0.001*

Notes: Mean values with asterix in the same row are statistically different from each other (p<0.05)

MIW: mean initial weight; MFW: mean final weight; MIL: mean initial length; MFL: mean final length; MWG: mean weight gain; SGR: specific growth rate; FI: feed intake; FCR: feed conversion ratio; PI: protein intake; PER: protein efficiency ratio; K_n: condition factor

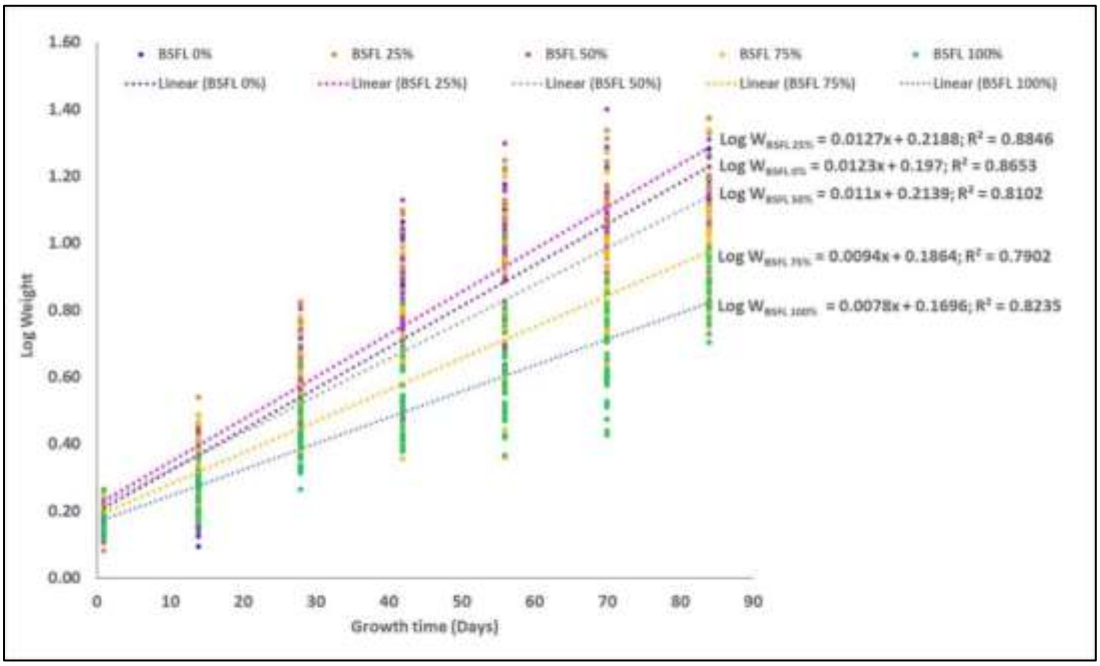

Figure 4.1: Regression slopes of Log Weight on Time (Age) of African catfish (*C. gariepinus*) fed BSFL based diets

4.1.2 Fish Growth Regression Slopes in Lengths

A graphical plot of length against time (days) for each treatment is shown in Figure 4.2. The Generalised Linear Model (GLM) of growth in weight with the diets as categorical treatments showed that there was adequate evidence that at least one of the slopes was significantly different. Multiple comparison using Fisher's Least Significant Difference (LSD) identified 4 homogenous groups. A visual examination of the plot showed that BSFL 25% was the best performing formulation while BSFL 100% showed the poorest performance with an average growth rate of 0.07% per day as compared to BSFL 25% with 1.3% growth rate per day.

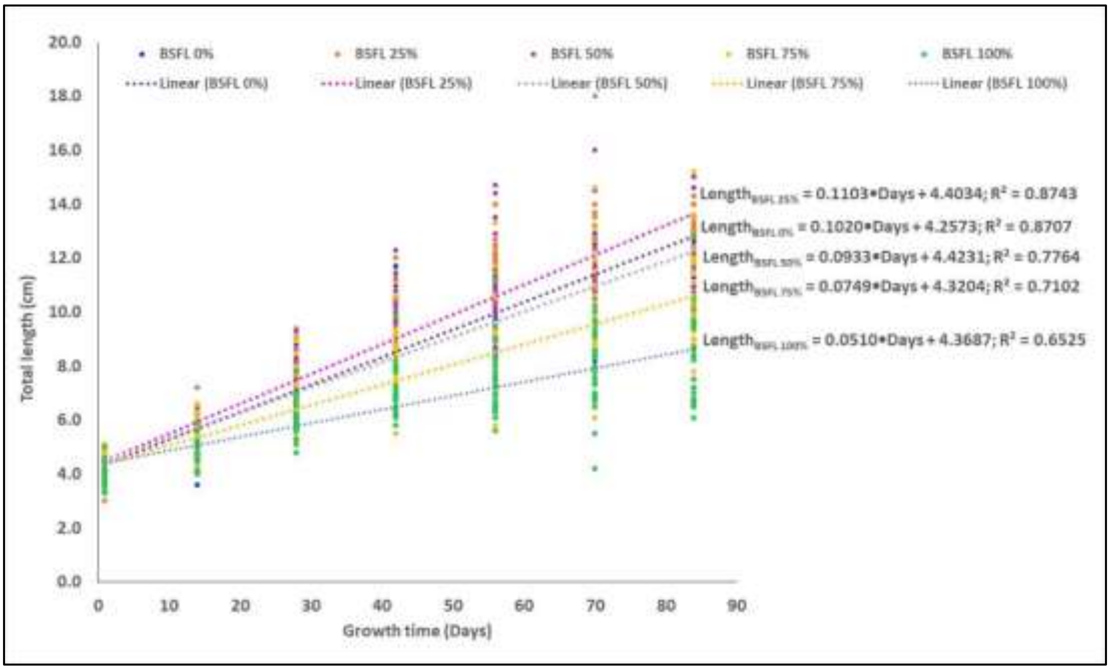

Figure 4.2: Regression slopes of length on Time (Age) of African catfish (*C. gariepinus*) fed BSFL based diets

4.1.3 Length-Weight Relationship (LWR)

The Length-weight relationship (LWR) among pairs of plotted data, values of coefficients of determination (R^2) and corresponding equation are demonstrated in Table 4.2. The value of the regression coefficient obtained from the LWR was 0.9827, 0.9861, 0.9826, 0.9706 and 0.8992 for fish fed on different BSFL inclusion levels of 0%, 25%, 50%, 75% and 100% respectively. There was a significant relationship between length and weight. From the regression equations in the Table 4.2 below, all treatments showed close to isometric growth pattern.

Table 4.2: Length-weight relationship of African catfish fed BSFL based diets

Treatment	Weight	Length	R^2
BSFL 0%	0.0059	3.0814	0.9827
BSFL 25%	0.0070	2.9802	0.9861
BSFL 50%	0.0075	2.9533	0.9826
BSFL 75%	0.0071	2.9825	0.9706
BSFL 100%	0.0073	3.0232	0.8992

4.1.4 Survival Analysis

The maximum mortality for BSFL0%, BSFL25%, BSFL50%, BSFL75% and BSFL 100% were 18, 20, 22, 19 and 21 fish. These fish deaths and time in days when the deaths occurred provided an arbitrary censored data for survival analysis. The meant time to death was between 60 and 64 days and was best described by the medial number of days mortality in which 50% deaths was censored for each treatment (Table 4.3).

Table 4.3: Cumulative time to failure/death of African catfish for each treatment

Treatment A	**Estimated Death Time (Days)**	**Standard Error**	**95.0% Normal CI**	
			Lower	**Upper**
Mean (MTTF)	62.6470	1.65472	59.4039	65.8902
Standard Deviation	18.6850	1.17690	16.5150	21.1401
Median	62.6470	1.65472	59.4039	65.8902
First Quartile(Q1)	50.0442	1.83523	46.4472	53.6412
Third Quartile(Q3)	75.2499	1.83531	71.6527	78.8470
Interquartile Range (IQR)	25.2057	1.58762	22.2784	28.5176
Treatment B				
Mean (MTTF)	64.3330	1.64888	61.1013	67.5648
Standard Deviation	18.3980	1.17296	16.2369	20.8468
Median	64.3330	1.64888	61.1013	67.5648
First Quartile(Q1)	51.9237	1.82881	48.3393	55.5082
Third Quartile(Q3)	76.7423	1.82891	73.1577	80.3269
Interquartile Range (IQR)	24.8186	1.58230	21.9032	28.1219
Treatment C				
Mean (MTTF)	62.2792	1.76547	58.8190	65.7395
Standard Deviation	20.4893	1.25445	18.1724	23.1016
Median	62.2792	1.76547	58.8190	65.7395
First Quartile(Q1)	48.4594	1.95772	44.6223	52.2964
Third Quartile(Q3)	76.0990	1.95778	72.2618	79.9362
Interquartile Range (IQR)	27.6396	1.69223	24.5142	31.1635
Treatment D				
Mean (MTTF)	60.6427	1.60500	57.4970	63.7885
Standard Deviation	19.3544	1.14111	17.2423	21.7253
Median	60.6427	1.60500	57.4970	63.7885
First Quartile(Q1)	47.5883	1.77998	44.0996	51.0770
Third Quartile(Q3)	73.6971	1.78003	70.2083	77.1859
Interquartile Range (IQR)	26.1087	1.53934	23.2595	29.3070
Treatment E				
Mean (MTTF)	61.4863	1.63572	58.2803	64.6922
Standard Deviation	19.7965	1.16266	17.6440	22.2116
Median	61.4863	1.63572	58.2803	64.6922
First Quartile(Q1)	48.1337	1.81396	44.5784	51.6890
Third Quartile(Q3)	74.8388	1.81402	71.2834	78.3943
Interquartile Range (IQR)	26.7051	1.56841	23.8014	29.9631

MTTF = Meant time to failure

The first and third quartiles showed that it took between 47 and 51 days to censor 25% mortality and between 73 and 76 days for 75% of the mortality. Probability plots on log-scale for survival against time (days) for each treatment used is shown in Figure

4.3. The plots showed that arbitrary censored approach using the Weibull distribution provided a relatively good fit of the data as most of the plotted points fell within the confidence limits. Testing of the equality of the fitted survival model was using the shape and scale parameters of the Weibull distribution showed no significant differences in scale and shape parameters considered simultaneously ($\square^{2}_{0.05(2),4} = 4.833$; *p-value* = *0.775*) nor was there any significant differences in the scale parameters considered individually ($\square^{2}_{0.05(2),4} = 1.9581$; *p-value* = *0.743*) or location parameter considered individually ($\square^{2}_{0.05(2),4} = 2.8746$; *p-value* = *0.579*).

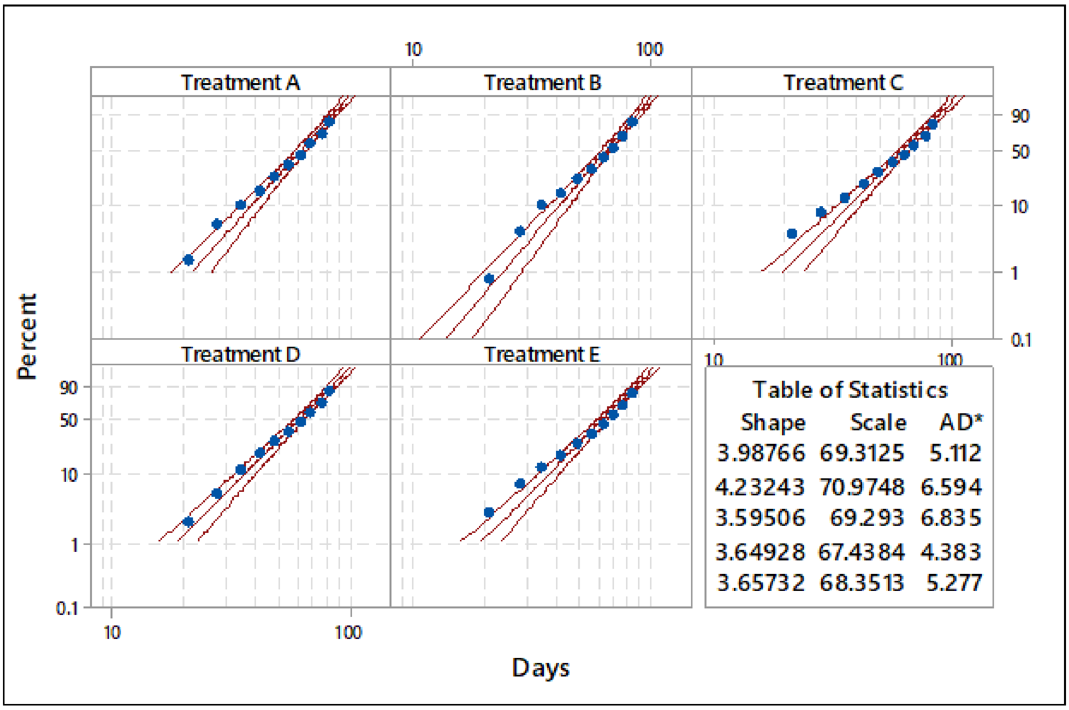

Figure 4.3: Probability plots for survival by days of African catfish (*C. gariepinus*) fed BSFL based diets

4.2 Water Quality Parameters

Results for quality of water that was used in culturing the African catfish fingerlings fed with BSFL based diets are presented in Table 4.4. The results showed that all the water quality parameters: temperature, dissolved oxygen, pH, ammonia and nitrate were statistically similar with $F_{0.05, 4}$=1.53, p-value = 0.001; $F_{0.05, 4}$=0.001, p-value = 0.001; $F_{0.05, 4}$=0.01, p-value = 0.001; $F_{0.05, 4}$=0.64, p-value = 0.001 and $F_{0.05, 4}$=0.55, p-value = 0.001, respectively.

Table 4.4: Physico-chemical water quality parameters recorded during the study

	Dietary treatments						
Parameter	**BSFL 0%**	**BSFL 25%**	**BSFL 50%**	**BSFL 75%**	**BSFL 100%**	**F-Value**	**P-Value**
Temperature (°C)	28.83±0.10[a]	28.56±0.10[a]	28.58±0.10[a]	28.58±0.10[a]	28.74±0.10[a]	1.53	0.190
Dissolved oxygen (mg/L)	3.27±0.08[a]	3.28±0.08[a]	3.28±0.08[a]	3.27±0.08[a]	3.27±0.08[a]	0.001	1.000
pH	7.49±0.02[a]	7.48±0.02[a]	7.48±0.02[a]	7.49±0.02[a]	7.48±0.02[a]	0.01	1.000
Ammonia	0.41±0.07[a]	0.40±0.07[a]	0.46±0.09[a]	0.47±0.09[a]	0.32±0.05[a]	0.64	0.639
Nitrate	0.02±0.010[a]	0.02±0.01[a]	0.02±0.01[a]	0.02±0.01[a]	0.02±0.01[a]	0.55	0.700

Mean values with similar superscripts in the same row are not statistically different from each other ($p>0.05$)

4.3 Carcass Composition

Fish carcass composition results are summarised in Table 4.5. Results indicated that dry matter, ash content, ether extracts, crude protein, crude fibre and nitrogen free extracts of fish fed with the experimental diets were significantly different across all the treatments with $F_{0.05, 4}$=147.97, p-value = 0.001; $F_{0.05, 4}$=128.44, p-value = 0.001; $F_{0.05, 4}$=882.25, p-value = 0.001; $F_{0.05, 4}$=98.77, p-value = 0.001; $F_{0.05, 4}$=653.84, p-value = 0.001, and $F_{0.05, 4}$=41.28, p-value = 0.001, respectively. However, the results also indicated that the crude protein, ash and nitrogen free extracts contents of BSFL 0% performed better than the other treatments. The results also indicated that BSFL 0% had poor dry matter and crude fibre contents than all other treatments.

Table 4.5: Proximate composition of the African catfish (*C. gariepinus*) fingerlings fed black soldier fly larvae-based diets

	Experimental fish carcass						
Parameter	**BSFL 0%**	**BSFL 25%**	**BSFL 50%**	**BSFL 75%**	**BSFL100%**	**F-Value**	**P-Value**
Dry matter	97.29±0.02[c]	98.11±0.02[a]	97.06±0.001[b]	97.06±0.01[e]	97.13±0.01[d]	1427.97	<0.001*
Ash	14.91±0.24[a]	14.00±0.06[b]	13.34±0.15[c]	13.59±0.09[bc]	10.69±0.07[e]	128.44	<0.001*
Ether extract	20.00±0.08[e]	22.66±0.03[d]	24.24±0.16[c]	26.05±0.16[b]	30.34±0.16[a]	882.25	<0.001*
Crude protein	58.18±0.08[a]	56.66±0.40[b]	55.31±0.43[b]	52.87±0.13[c]	50.12±0.38[d]	98.77	<0.001*
Crude fibre	1.36±0.04[e]	2.41±0.02[d]	3.47±0.04[c]	5.35±0.13[b]	7.54±0.16[a]	653.84	<0.001*
Nitrogen free extracts	5.55±0.21[a]	4.27±0.45[b]	3.65±0.19[b]	2.16±0.23[c]	1.31±0.12[c]	41.28	<0.001*

Mean values with asterix in the same row are statistically different from each other (p<0.05)

4.4 Economic Analysis

Data on economic performance is shown in Table 4.6. BSFL 0% had the highest (P<0.05) feed cost per kilogram (KES 139.75) among all the treatments. The total feed cost was also significantly higher in BSFL 0% (KES 43.18) (P>0.05) and it reduced with a corresponding increase in BSFL meal inclusion in the diets. Harvested weight and value of harvested fish increased (P<0.05) with fish meal substitution levels from 0 to 25% but dropped drastically from 50 to 100% fish meal substitution diet. Feeding the African catfish fingerlings with BSFL based diets reduced significantly (P>0.05) the incidence cost compared to BSFL 0%. BSFL 0% had the highest incidence cost (KES 99.99) while BSFL 100% (KES 59.93) had the lowest incident cost. However, BSFL 25% (KES 70.23), BSFL 50% (KES 83.61) and BSFL 75% (KES 72.56) were not significantly different (P>0.05). On the contrary, the African catfish fingerlings fed on BSFL based diets increased significantly (P<0.05) the profit index compared to BSFL 0%. BSFL 100% as well as 25% had the highest profit index of (KES 5.06) and (KES 4.28) respectively while BSFL 0% had the lowest profit index (KES 3.00).

Table 4.6: Economic analysis of the African catfish (*C. gariepinus*) fingerlings fed black soldier fly larvae-based diets

	Experimental diets					
Parameter	**BSFL 0%**	**BSFL 25%**	**BSFL 50%**	**BSFL 75%**	**BSFL100%**	**P-Value**
Feed cost/Kg (KES)	139.75 ± 0.53^{a}	137.08 ± 1.15^{ab}	134.41 ± 1.15^{bc}	131.74 ± 1.17^{cd}	129.07 ± 1.14^{d}	<0.0001
Feed fed (Kg)	0.31 ± 0.01^{a}	0.28 ± 0.02^{a}	0.23 ± 0.01^{b}	0.16 ± 0.01^{c}	0.10 ± 0.00^{d}	<0.0001
Total feed cost (KES)	43.18 ± 1.17^{a}	38.66 ± 1.15^{b}	30.51 ± 1.16^{c}	20.68 ± 1.16^{d}	13.42 ± 1.14^{e}	<0.0001
Harvest weight (Kg)	0.43 ± 0.01^{b}	0.52 ± 0.01^{a}	0.37 ± 0.00^{c}	0.28 ± 0.00^{d}	0.22 ± 0.00^{e}	<0.0001
Value of fish (KES)	129.60 ± 3.15^{b}	156.63 ± 3.80^{a}	109.51 ± 0.34^{c}	85.49 ± 0.87^{d}	67.09 ± 0.94^{e}	<0.0001
Incident cost (KES)	99.99 ± 2.19^{a}	70.23 ± 1.70^{bc}	83.61 ± 3.45^{b}	72.56 ± 3.79^{bc}	59.93 ± 4.46^{c}	<0.0001
Profit index (KES)	3.00 ± 0.07^{c}	4.28 ± 0.11^{ab}	3.60 ± 0.15^{bc}	4.16 ± 0.22^{ab}	5.06 ± 0.39^{a}	0.001

Mean values with different superscripts in the same row are statistically different from each other ($p<0.05$

CHAPTER FIVE

DISCUSSION

5.1 Growth Performance of African Catfish fed BSFL based diets

5.1.1 Growth Performance

Concurrently the results of the present study illustrated that the diet in which 25% of fishmeal protein has been replaced by BSFL meal gave rise to the best results without negative consequences for growth performance, when compared to all the other treatment diets. These results are in agreement with those of previous studies which suggested an optimum fish meal replacement level of 25% using insect meal (Teye-Gaga, 2017; Xiao *et al*., 2018) in different aquaculture species. Our finding strongly corroborates with that of Xiao *et al*. (2018), who observed that substituting fish meal with 25% BSFL produced the best results in growth performance indices as well as the immune index of Yellow catfish (*Pelteobagrus fulvidraco*). These results also strongly agrees with those of a previous study which indicated that BSFL could replace up to 25% fishmeal in the diet of Nile tilapia (*O. niloticus*) without adverse effects on growth performance (Teye-Gaga, 2017). On the contrary, our results for growth performance as well as feed utilization differ from those of Limbu *et al*. (2022), who reported high growth performance and feed utilization in Nile tilapia (*O. niloticus*) fry that were given diets supplemented with BSFL meal up to 75%.

When replacing fishmeal with BSFL meal from 50% to 100% in fish diets, growth of *C. gariepinus* was strongly suppressed, while feed intake and protein intake reduced as well as increased feed conversion ratio and performance efficiency ratio. Our present results strongly corroborates with researches which reported that Nile tilapia (*O. niloticus*) fry, fingerling which were fed diets containing BSFL 100% had poor growth performance (Rana *et al*., 2015; Muin *et al*., 2017; Teye-Gaga, 2017; Devic *et al*., 2018). Total replacement of fishmeal with insect meals has usually been unsuccessful and performed poor, probably because of the dietary imbalances and deficiencies (Henry *et al*., 2015). Incorporating BSFL meal in fish diets is possible but limited by low nutritive value (Kroeckel *et al*., 2012). Lock *et al*. (2016) indicated that replacing fishmeal with 100% BSFL meal increased the level of thiobarbituric acid-reactive substances, which resulted in lower palatability of the diet. Li *et al*. (2017) indicated that at least 50% of fishmeal could be replaced with BSFL meal in juvenile Jian carp (*Cyprinus carpio*), but dietary stress and intestinal histopathological damage were observed when replacement levels exceeded 75%. Another study by Burr *et al*. (2012) highlighted that replacing fishmeal with high percentages of BSFL meal resulted in decreased palatability which reduced feed intake and nutrient absorption. Kroeckel *et al*. (2012) observed that increasing levels of BSFL meal in diets of juvenile turbot (*Psetta maxima*) reduced palatability, acceptability and feed intake of fish. Diets in which fishmeal is substantially replaced with alternative protein sources especially those that contain the anti-nutritional factors (ANFs) can reduce the palatability of the feed (Kroeckel *et al*., 2012). Although this study did not determine the types and concentrations of ANFs for the various test ingredients such as BSFL meal, it had been widely reported that a significant increase in the amount of BSFL meal in fish diets could gradually inhibit the growth of fish (Kroeckel *et al*., 2012; Talamuk, 2016; (Xiao *et al*., 2018; Caimi *et al*., 2020).

Decreased fish growth performance as well as feed utilization with a corresponding increase in the dietary insect meal inclusion could be due to the substantial increase in chitin content. Chitin is a component of the exoskeleton in invertebrates (Talamuk, 2016), that is relatively resistant to degradation and not easily digested by animals (Shoba *et al*., 2016) including several fish species because these fish lack chitinase activity (Rust, 2002; Zhou *et al*., 2018). Insect chitin affects digestibility of nutrients (Belforti *et al*., 2015). High chitin contents with a corresponding increase in the dietary BSFL meal inclusion levels were postulated to decrease feed intake, growth and digestibility of juvenile Turbot (*Psetta maxima*) (Kroeckel *et al*., 2012), Yellow catfish (*Pelteobagrus fulvidraco* (Xiao *et al*., 2018), Jian carp (*Cyprinus carpio* var Jian) (Zhou *et al*., 2018). and Thai climbing perch (*Anabas testudieneus)* (Mapanao *et al*., 2021).

5.1.2 Relative Condition Factor (K_n)

In this study, the relative condition factor (K_n) values of African catfish fingerlings across all the treatments were greater than 1.0 hence the condition factors of *C. gariepinus* fingerlings were not affected by replacing fishmeal with BSFL meal at all levels. According to Anani and Nunoo (2016), the condition factor greater than 1.0 implies good health condition of fish. These condition factor values which are high could be due to good water quality parameters maintained throughout the experiment and the high nutritional quality of the feeds. Similar results were obtained in Atlantic salmon (Lock *et al*., 2016), Yellow catfish (*Pelteobagrus fulvidraco* (Xiao *et al*., 2018), Thai climbing perch (*Anabas testudieneus)* (Mapanao *et al*., 2021), and Nile tilapia (*O. niloticus*) (Tippayadara *et al*., 2021; Limbu *et al*., 2022), in which the inclusion of BSFL meal up to 100% was used.

5.1.3 Length-Weight Relationship (LWR)

From the results the values of b were close to 3. These values are close to the ideal fish shape of b = 3 (Datta *et al*., 2013) and they fall within the range of 2 – 4 recommended for freshwater fishes (Anani & Nunoo, 2016; Migiro *et al*., 2014). There results showed that black soldier fly had no any negative effects on the length-weight relationship of the catfish fingerlings. Similar findings were reported in Nile tilapia (*Oreochromis niloticus*) (Teye-Gaga, 2017).

5.1.4 Survival Analysis

It was also notable that replacing fishmeal with BSFL at all levels in diets used did not affect survival of the *C. gariepinus* fingerlings in this study. These results are in agreement with previous studies that use BSFL meal as partial or total replacement of fishmeal in diets for Pacific white shrimp (Cummins *et al*., 2016), European sea bass (Abdel-Tawwab *et al*., 2020) and Nile tilapia (Wachira *et al*., 2021; Limbu *et al*., 2022).

5.2 Water Quality

Water quality parameters in aquaculture practices are those factors that directly affect fish metabolism, feed intake and nutritional efficiency (Ercan *et al*., 2015). In this present study, the water quality parameters (temperature (ºC), dissolved oxygen (mg/L), pH, ammonia and nitrate) values recorded throughout the rearing period were within the recommended optimum range for all the treatments, thus did not have any adverse effect on the growth of the *C. gariepinus* fingerlings. These values are similar to those of Talamuk (2016) and Matanda *et al*. (2017). These suitable water quality parameters that were recorded in the experimental water tanks could have been attributed to good water management practices, such as maintaining the water levels in the tanks by regularly flushing out and topping up, thus replenishing the culture system with freshwater. Also, the use of high-quality diets, might have resulted in high feed intake and digestibility; avoiding feed waste by giving the right amount of feed based on the recommended feed rate

5.3 Carcass Composition

In the present study, whole-body proximate composition of fish was affected by the inclusion of BSFL meal as an alternative ingredient for replacing fish meal in the feeds. Decreased protein in carcass composition of *C. gariepinus* fingerlings with a corresponding increase in inclusion levels of dietary BSFL meal was observed. Similar findings were reported in Nile tilapia (*Oreochromis niloticus*) (Teye-Gaga, 2017), Yellow catfish (*Pelteobagrus fulvidraco*) (Xiao *et al*., 2018), Thai climbing perch (*Anabas testudineus*) (Mapanao *et al*., 2021). This could relate to excess chitin replacement in BSFL meal, which reduced the palatability of the diets, thereby reducing protein intake, protein digestibility and absorption (Kroeckel *et al*., 2012). Feed intake was also found to be reduced with decreasing level of fishmeal in the diets of Nile tilapia and Rainbow trouts (Ogunji *et al*., 2008; Stamer *et al*., 2014). Though the present study did not focus on amino acid composition of the diets, the disparities could also be attributed to reduced quality of amino acids especially the essential amino acids. Kroeckel *et al*. (2012) reported that fishmeal contains superior quality of essential amino acids compared to BSFL meal. Increasing inclusion levels of the BSFL meal and decreasing level of fishmeal reduce the quality of dietary protein and may affect digestibility.

With increasing amounts of BSFL meal in diets, whole-body nitrogen free extracts content decreased significantly mainly due to a significant decreased feed intake and therefore low carbohydrates intake. Kroeckel *et al*. (2012) reported a decrease in gross energy content with increased amounts of housefly maggots due to decreased feed intake and therefore low energy intake. Crude fibre content of the whole-body composition might have been also affected by dietary treatments. Increasing BSFL meal inclusion level in the feeds, increased the crude fibre content of the whole-body composition due to the substantial increase in chitin content. BSFL has a high fibre content (Mulianda *et al*., 2020). 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). However, the increase in BSFL meal in the experimental diets might have increased the proportion of chitin per unit of dry matter (Zhu *et al*., 2016), which was absorbed by the fish.

The whole-body fish ether extracts increased significantly with a corresponding increase in inclusion levels of the dietary insect meal. 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 (*O. niloticus)* fry, fingerlings. Our results are also in line 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 observed that the crude lipid content of the whole-body and muscle tissue of rainbow trout decreased significantly as the amount of BSFL increased (Sealey *et al*., 2011; Kroeckel *et al*., 2012). These researches suggested that the defatting process of BSFL influences the level of the lipids and this may have reduced the lipid bioavailability (Kroeckel *et al*., 2012). The experimental feeds also affected the ash content of the fish carcasses. According to Hu *et al*. (2017), insect exoskeletons are rich in mineral salts, therefore substituting fishmeal with BSFL meal might have changed the mineral content of the experimental diets and affect the ash content of fish carcass.

5.4 Economic Analysis

In the present study, BSFL meal was utilised to either partially or completely replace fish meal and resulted in different economic performances in terms of incidence costs and profit index. The costs of producing a kilogram of feed in this study was highest in diets containing BSFL 0% and this translated into higher incidence costs. This is attributed to the higher cost of fish meal (KES 250). On the other hand, the production costs of BSFL 100% were the lowest, which may be related to the low market price of black soldier fly larvae (KES 150), which formed the bulk of the protein in the diet that had 100% BSFL meal.

The economic performance showed positive net-returns for all the experimental diets that were used in the present study. The variation in economic performance of the diets was attributed to varied principal protein sources which had different prices. The economic evaluation for feed production showed that replacing fish meal by BSFL meal minimised the cost of producing the diets. The economic results also showed that BSFL 75% and BSFL 100% diets had the highest profit index even though they had lower final weight gain. This was due to the low market price of black soldier fly larvae. (Table 3.4). In order to maximise fish farm profits, the cost of feed must be lowered, and a significant amount of effort must be put toward discovering alternatives protein sources to fish meal either from animals, plants, or insects. (Limbu *et al*., 2022). However, the fish that are produced using these diets will take significantly longer to attain market size. This strongly agrees with Ogunji *et al.* (2008) and Kirimi *et al.* (2016), who said that in relation to rearing time, the rate of fish development is reduced when alternative protein sources are used in *O. niloticus* diets, resulting to extended raising time. Due to the relatively cheap cost of the protein sources, the total cost of rearing the fish would be reduced, which would compensate for the slowed growth and time wasted, ultimately leading to an increase in profitability. On the other hand, this may not be fully beneficial for intensive commercial farmers who are aiming to make big profits in the quickest amount of time feasible, but it will be of tremendous use for small to medium size semi-intensive farmers.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the objectives of this study, investigations carried out and the results obtained, the major conclusions are:

1. Black soldier fly larvae meal protein could be used to partially replace fish meal protein in the diet of African catfish (*C. gariepinus*). Replacement at 25% BSFL meal improved the growth performance as well as feed utilization hence, the null hypothesis was rejected at 25% BSFL inclusion level.
2. Replacing fishmeal with BSFL meal in African catfish fingerling diets showed decreased concentration of crude protein, ash, nitrogen free extracts, and increased the ether extracts and fibre contents of the whole-body fish composition, hence, the null hypothesis was rejected.
3. The total costs, harvest weight and value of fish were found to be higher for the 25% replacement as compare to all the other compositions even when the amounts fed and the feed cost per kg were not significantly different from wholly fishmeal-based diet. The profit indices were better for all BSFL based diets as compared to whole fishmeal-based diet hence, the null hypothesis was rejected at 25% BSFL inclusion level.

6.2 Recommendations

From the conclusions of this study, the following recommendations should be considered for adoption of BSFL as alternative to fishmeal in aquafeeds for the African catfish:

1. The utilisation of BSFL meal at substitution rate of 25% is recommended for enhancing the growth performance of fish, especially for the weight and daily length gains as well as better survival.
2. Even though the replacement of fishmeal with BSFL reduced the total protein contents, it is still recommended that the benefit of reduced costs and enhanced weight and length outweighs the slight reduction in crude protein, ash, nitrogen free extract and 25% level of replacement should be adopted.

3. The better economic performance of the 25% BSFL based diet provides better profit index and should be adopted for feed formulation and field trials.

The following recommendations are for further research:

1. Evaluating the effectiveness, acceptability as well as the utilisation of black soldier fly larvae meal by different fish species is needed
2. Experimental diets were fed to African catfish fingerlings during their early stages for approximately twelve weeks. Further studies are recommended to determine the growth trends of the catfish fed on the same diets to maturity.
3. Further analysis of the experimental fish should be done to determine amino acid composition and other micronutrients such as minerals, vitamins and their effects on the growth rate of *C. gariepinus* fingerlings.
4. Further studies should be done to compare the growth performance of African catfish fed on BSFL-based diets and the conventional feeds from the market.
5. In order of ascertain the commercial prospect of black soldier fly larvae meal diets, sensory evaluation on African catfish fed BSFL-based diets should be carried out.

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APPENDICES

Appendix 1: Approval Letter JOOUST Board of Postgraduate Studies

JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE & TECHNOLOGY

BOARD OF POSTGRADUATE STUDIES

Office of the Director

Tel. 057-2501804
Email: bps@jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

Our Ref: A451/4229/2020

Date: 28th February 2022

TO WHOM IT MAY CONCERN

RE: GENERAL BEVEN MUNDIDA - A451/4229/2020

The above person is a bonafide postgraduate student of Jaramogi Oginga Odinga University of Science and Technology in the School of Agricultural and Food Sciences pursuing Master of Science in Food Security and Sustainable Agriculture. He has been authorized by the University to undertake research on the topic: **"Growth Performance and Yield of African Catfish *(Clarias Gariepinus Burchell, 1982)* Fed on Black Soldier Fly *(Hermetia Illucens Linnaeus, 1758)* Larvae Based Diets".**

Any assistance accorded him shall be appreciated.

Thank you.

Prof. Dennis Ochuodho
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

Appendix 2: Letter of Ethical Review Committee Approval

JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY

DIVISION OF RESEARCH, INNOVATION AND OUTREACH
JOOUST-ETHICS REVIEW OFFICE

Tel. 057-2501804
Email: erc@jooust.ac.ke
Website: www.jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

OUR REF: JOOUST/DVC-RIO/ERC/E3

7th April, 2022

General Beven Mundida
A451/4229/2020
JOOUST

Dear Mr. Mundida,

RE: APPROVAL TO CONDUCT RESEARCH TITLED "GROWTH PERFORMANCE AND YIELD OF AFRICAN CATFISH *(CLARIAS GARIEPINUS BURCHELL*, 1822) FED ON BLACK SOLDIER FLY *(HERMETIA ILLUCENS*, 1758) LARVAE DIETS"

This is to inform you that JOOUST ERC has reviewed and approved your above research proposal. Your application approval number is **ERC 29/4/22-23.** The approval period is from 7th April, 2022–6th April, 2023.

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations and violations) are submitted for review and approval by JOOUST IERC.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to NACOSTI IERC within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks of affected safety or welfare of study participants and others or affect the integrity of the research must be reported to NACOSTI IERC within 72 hours.
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to JOOUST IERC.

Prior to commencing your study, you will be expected to obtain a research permit from National Commission for Science, Technology and Innovation (NACOSTI) https:oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

for

Prof. Francis Anga'wa
Chairman, JOOUST ERC

Copy to: Deputy Vice-Chancellor, RIO   Director, BPS   DEAN, SAFS

/dm

Appendix 3: NACOSTI Research License

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 664670

Date of Issue: 04/May/2022

RESEARCH LICENSE

This is to Certify that Mr.. General Beven Mundide of Jaramogi Oginga Odinga University of Science and Technology, has been licensed to conduct research in Siaya on the topic: Growth performance and yield of African catfish (Clarias gariepinus Burchell, 1822) fed on black soldier fly (Hermetia illucens, 1758) larvae diets for the period ending : 04/May/2023.

License No: NACOSTI/P/22/17210

664670

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR
SCIENCE, TECHNOLOGY &
INNOVATION

Verification QR Code