

**POTENTIAL OF BLACK SOLDIER FLY LARVA (*Hermetia illucens* L.1758) AS AN
ALTERNATIVE PROTEIN SUPPLEMENT IN NILE TILAPIA
(*Oreochromis niloticus* L.) FEED**

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**A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirements
for Award of Degree of Master of Science in Food Security and Sustainable
Agriculture of Jaramogi Oginga Odinga University of Science and Technology**

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted to any university or institution for an award of degree or diploma.

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Approval

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DEDICATION

This work is dedicated to my mother, Jane Adhiambo Odhiambo, who has always loved me unconditionally and whose good example has taught me to strive to achieve for what I want.

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ABSTRACT

With fish depletion in Lake Victoria, there is an emerging competition for silver cyprinid fish *Rastrineobola argentea* ('Omena') between human consumption and fish aquaculture feed formulation. Subsequently, fishmeal has increasingly become expensive with feed cost accounting for around 70% of variable costs in fish farming. Therefore, this study focused on using black soldier fly larva as a substitute for fishmeal with the following objectives 1. To evaluate the growth performance of *O. niloticus* fed on a diet supplemented with *H. illucens* larva meal as a source of protein and; 2. To identify the most cost effective diet supplemented with *H. illucens* larvae as a source of protein for *O. niloticus*. The study focused on using *H. illucens* larva as a supplement in *O. niloticus* diets as an alternative to fishmeal. For objective one, five test diets were formulated with strategic inclusions of *H. illucens* at (0, 25, 50, 75 and 100 %). Growth parameters namely length, weight and survival data were sampled fortnightly. Objective 2 was investigated by using the enterprise budgets on the relative profitability of the fish fed on varying *H. illucens* levels and fishmeal. Statistical comparisons were performed by One Way Analysis of Variance (ANOVA), One-way Analysis of Covariance (ANCOVA) and multiple linear regression analysis using Statgraphics ver16 and R-Statistical Software version 3.5.3. After controlling for time (days), there was a significant difference in the treatment effect on length ($p < 0.05$). Days equally had a significant effect on growth performance ($p < 0.05$). Moreover, the interaction effect between treatment and time was significant ($p < 0.05$). In terms of weight, after controlling for time (days), there was a significant difference in the treatment effect on weight ($p < 0.05$). Days equally had a significant effect on growth performance (length and weight gain) ($p < 0.05$). Moreover, the interaction effect between treatment and time was significant ($p < 0.05$) with R^2 of 0.98 for length while weight ($p < 0.05$) with an R^2 of 0.96. This study found that *O. niloticus* fed diets containing 25% *H. illucens* outperformed the control (FM) treatment in growth performance. There were no significant differences between the FM (control) and feed supplemented with *H. illucens* at 50%. However, growth performance declined at 75 and 100%, which led to the conclusion that increased levels of *H. illucens* in the diet due to inadequate supply of amino acids and increased chitin levels caused a decline in growth. In terms of economic analysis, *O. niloticus* fed increasing levels of *H. illucens* was more profitable at 50%, 75% and 100%. These findings indicated that *O. niloticus* feed can effectively be supplemented with *H. illucens* as a protein without adverse effects on growth performance. The study clearly indicates that aquaculture farmers and feed manufacturers can use *H. illucens* instead of fishmeal in feeds thereby lowering production costs and increasing food security. Furthermore, farmers should increase their economies of scale and only sell fish once they reach market size in order to increase aquaculture profitability and meet the food and nutritional security agenda.

Key words: *O. niloticus*, production cost, fishmeal, black Soldier fly larva, food security and growth performance.

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LIST OF ABBREVIATIONS

ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
AOAC	Association of Analytical Chemists
BSF	Black Soldier Fly
CP	Crude Protein
DO	Dissolved Oxygen
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics Division
FCR	Food Conversion Ratio Grams
gm	Geographic Information System Gross
GISGP	Profit
JOOUST	Jaramogi Oginga Odinga University of Science and Technology Kenya
KALRO	Agriculture Livestock and Research Organization Kilograms
Kg	Kenya National Bureau of Statistics Kenya
KNBS	Marine Fisheries Institute
KMFRI	litre
l Mg	Milligram
MoALF	Ministry of Agriculture Livestock and Fisheries
NRC	National Research Council
OECD	Organization for Economic Cooperation and Development
SDGs	Sustainable Development Goal
UN DESA	United Nations, Department of Economic and Social Affairs. United
USAID	States Agency for International Development
WFP	World Food Program
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background Information

According to the United Nations, the world's population will increase to 8.5 billion in 2030, 9.7 billion in 2050 and 10.9 billion by 2100 (UNDESA, 2019). These projections suggest that, feeding the population by 2050 will require an increase of about 70% in food production (FAO, 2012). Although widespread food insecurity persists, Sub-Saharan Africa has some of the worst cases. In 2017, 33.9% of Sub-Saharan Africans were estimated to be food insecure (FAO *et al.*, 2018). While the human population is expected to grow at a rate of less than 1% annually from 2015 to 2020 (UNDESA, 2019), annual fish consumption is expected to grow at 1.3 % (OECD-FAO, 2019). As a result, more investments must be made in the aquaculture sector to sustain the capture fisheries while meeting fish demand and increasing food security.

Recent increase in fish demand has caused over exploitation of wild fish. As a result, increased aquaculture production will supplement capture fisheries whilst still satisfying fish and fish products consumer demands. The growth of the aquaculture sector will also require affordable feed production so as to meet the farmers demand.

Fishmeal is a popular protein source in fish feed. It is palatable and provides essential nutrients that promote healthy fish growth. Most fish species can also easily digest its high-quality amino acids (NRC, 2011). However, a major limiting factor to the vibrant growth of aquaculture is the limited supply of fishmeal leading to rise in production costs in the sector. Thus, low cost and readily available feed ingredients are fundamental to sustain food security through aquaculture.

According to KMFRI (2017), *O.niloticus* is a freshwater cichlid that produces nearly 80% of all aquaculture. The African catfish *Clarias gariepinus*, comes in second, accounting for about 21% of aquaculture production (Kim *et al.*, 2014). *O. niloticus* feeds lower in the food chain majorly on phytoplankton, zooplankton and detritus. It thrives well in water

temperature of 20- 35°C. Normally, sexual maturation is attained between four to six months (El-Nahal *et al.*, 2019).

The male Nile tilapia (*O.niloticus*) grow almost twice as faster compared to the female, they also appear to be fleshier and larger (Bhatta *et al.*, 2012).To ensure increased profits and enhanced food security mono sex culture practice is more preferred as the culture period is reduced with more output.

The increasing prices of feed protein sources used in fish feed formulation is the main challenge in aquaculture, as the global volatile supply and demand variables determine commodity prices. In addition, fluctuations in petroleum fuel prices result in increases in feed prices thus reducing the already thin profit margins eroding sustainable production (Fontes *et al.*, 2019). Overall, feeds account for roughly 50 to 80 % or more of cost of production in fish farming (KMFRI,2017).Fish feed manufacturers and farmers can reduce the *O. niloticus* feed expenses in three ways; i) by decreasing the total feed used in growth of marketable fish (Ochieng *et al.*, 2015). ii)by decreasing crude protein levels by amino acid supplementation (Ouma, 2019) and iii) using alternative low-cost protein sources in place of fishmeal, or lowering feed manufacturing costs by using pellet processing rather than expensive extrusion processing (Bolivar *et al.*, 2011).

Fish meal is preferred in fish diets as a protein source because it is a naturally balanced feed ingredient rich in protein, energy, and minerals (Cho and Kim, 2011). Fishmeal, the main ingredient used in aqua feed formulation, is restricted in supply, expensive globally and has led to the reduction of wild fisheries. Hence the hunt for alternative ingredients to fishmeal has intensified. Insects, which provide a readily available and in-expensive source of protein, have not been exploited in this regard. Therefore, more studies must be conducted on the utilization of insects as feed ingredients.

Insect meals are more preferred as alternative protein ingredients in animal feeds and particularly are important natural source of food for both marine and freshwater fish species

(van Huis *et al.*, 2015). Insects are composed of fluctuating amounts of other nutrients such as essential amino acids, minerals, lipids and vitamins, depending on the life cycle, rearing conditions and substrates used. Generally, studies show that insects' crude protein content is relatively high as compared to fishmeal (Oloo, *et al.*, 2020). Therefore, including insect proteins as commercial feed ingredient could help fish farmers increase their productivity. Furthermore insects can be reared in large quantities using small amounts of land water or feed (van Huis *et al.*, 2013). The black soldier fly, the yellow mealworm and common housefly are potential animal feed resources (Sogari *et al.*, 2019).

Black soldier flies (*Hermetia illucens*) are globally distributed and unlike the common housefly (*Musca domestica*) are considered as neither a pest nor a transmitter of hazardous pathogens (Wang and Shelomi, 2017). Furthermore, the larva can be produced cheaply and with little environmental impact using manures and food scraps (Nyakeri *et al.*, 2017), which lowers feed costs and increases fish farming productivity. Each larva can consume between 25 and 500 mg of fresh matter daily (Bondari and Sheppard, 1987). Under ideal conditions of around 30°C, the growth period can last up to 45 days (Cannella *et al.*, 2016). The larvae can eliminate pathogenic microorganisms, waste odours, and housefly oviposition, which benefits environmental conservation and sanitation (Wang and Shelomi, 2017). Their nutritional value depends on the feed substrates they consume. Crude protein levels usually range from 28 to 48% and lipid levels from 12 to 42% (Barragan-Fonseca *et al.*, 2017). With the exception of omega-3 fatty acids, the nutritional value of fishmeal is comparable to that of *H. illucens* larva. They have an amino acid profile similar to fishmeal and can be a good source of lipids, depending on the food used to raise the larvae (English *et al.*, 2021). The lipid profile of *H. illucens* larva can be supplemented with appropriate feeds such as fish offal (St-Hilaire *et al.*, 2007).

The crude protein requirement for *O. niloticus* is approximately 30% during the immature gonadal growth stage and approximately 40% at the reproductive stage (Subandiyono and Hastuti, 2020). The common source of protein in *O. niloticus* diets such as the *Rastrineobola argentea* (silver cyprinid fish) contains about 40 % crude protein (Veldkamp

and Vernooij, 2019).

Aquaculture's large-scale development has resulted in significant trade-offs and limitations. Despite rapid advancements in feeding technology, the industry still requires expanded feed resource base. Expensive feeds and a scarcity of high-quality fingerlings have been identified as major impediments to fish farming in the country. For commercial fish farming to succeed in Kenya, operational costs such as feed, transportation and storage must not exceed farmer profits. To spur the aquaculture sector in Kenya, there is a need to reduce production costs. This study examined the effect of dietary supplementation *H. illucens* larva on growth performance and economic performance on of *O. niloticus*.

1.2 Statement of the Problem

Fisheries is one of the primary sources of livelihood for the Lake Victoria region. However, the fish population has gradually declined over the years. The dwindling fish population has been caused by the massive growth of water hyacinth, overfishing and water pollution (Nyamweya *et al.*, 2020). In 2019, Lake Victoria's fish output accounted for 62.5% of the national annual fish output, while the aquaculture sector contributed about 12.8% of the fish production (KNBS, 2020).

Due to the decline of the fish population in Lake Victoria and the government's primary goal to increase incomes and reduce food and nutrition insecurity in Kenya, aquaculture (cage aquaculture and fish ponds) has been supported through the economic stimulus program (Munguti *et al.*, 2014). Although aquaculture has increased fish production in Kenya, it has been neglected by Kenyans due to the high costs of feeds. Fishmeal, the main source of protein in *O. niloticus* diets, is the main cause of the high feed cost. The majority of farmers struggle to sustain fish farming due to the high cost of commercial feeds (Lucas *et al.*, 2019). Fishmeal is the main source of protein for many fish feed processors, resulting in competition for fish and fish products between industries and human consumers. The high demand of fishmeal and its limited supply in the market due to seasonality has created a need for alternative protein sources in aquaculture. Therefore there is a potential for the *H. illucens* to

play a role as an alternative protein source for fish such as *O. niloticus*, catfish and rainbow trout.

The *H. illucens*, which contains about 49.5% crude protein compared to the 40.3% in fishmeal (Veldkamp and Vernooij, 2019) offers a readily available protein source for the aquaculture sector. However few studies have focused on productivity and economic viability based on *H.illucens* larva meal as a protein supplement in fish feeds. Based on its availability, low cost of production, biological value, availability, fast growth and nutrient utilization, the *H. illucens* is quite promising in lowering aquaculture costs through its use as a protein source in aquaculture feeds. Against this background, this study aimed to assess the effect of dietary supplementation with *H.illucens* larvae on the growth and economic performance of *O. niloticus* in an aquaculture production system.

1.3 Objectives of the Study

1.3.1 General Objective

To evaluate the potential contribution of *H.illucens* as a protein supplement in aquaculture fish production system.

1.3.2 Specific Objectives

1. To evaluate the growth performance of *O. niloticus* fed on a diet supplemented with *H.illucens* larva meal as a source of protein.
2. To identify the most cost effective diet supplemented with *H.illucens* larvae as a source of protein for *O.niloticus*.

1.4 Hypotheses

1. There is no significant difference in the growth performance of *O. niloticus* fed on a diet supplemented with *H.illucens* larva as a source of protein.
2. There is no significant difference in the production cost of *O. niloticus* fed a diet supplemented with *H. illucens* as a protein source.

1.5 Justification of the Study

Globally, the aquaculture sub-sector is quite promising in meeting consumers demand for fish and a major livelihood source for a large population who benefit directly and indirectly from aquaculture and its value chain. The number of cage cultures and fishponds in Kenya has massively increased due to the support of the Kenyan government economic stimulus programme (Munguti *et al.*, 2014). In 2019, fish farming contributed about 12.8 % of the of Kenya's total fish output with an increase of 20.9 % from 15,300 tonnes produced in 2018 to 18,500 tonnes in 2019 (KNBS, 2020). However, aquaculture sub-sector is faced with costly commercial fish feed that threatens sustainability of the sector (KMFRI, 2017).

Normally the supply of the silver cyprinid fish *Rastrioneobola argentea* is limited and cannot meet consumer's demand leading to escalating feed costs. Fish farmers and industrial fish feed manufacturers can use insect meals as an alternative protein source (Fontes *al.*, 2019). *H. illucens* can also replace up to 50% of fishmeal without adversely impacting feed conversion ratios (FCR) or weight increase in *O.niloticus* (Muin *et al.*, 2017).

Farmers and feed manufacturers can calculate the cost and benefits of producing *H. illucens* to feed *O. niloticus* fingerlings based on economic profitability index of *H. illucens* larval meal as a feed element in *O. niloticus* diets. There are established colonies of *H. illucens* in Kenya such as JOOUST University and the International Centre of Insect Physiology and Ecology (ICIPE) insect farms. Agribusinesses of *H.illucens* insect farms such as Ecodudu and Kiamumbi aquaculture projects have also been set up.

The growth performance and digestibility of insect meals on *O. niloticus* have been conducted in several studies (Fontes *et al.*, 2019; Webster *et al.*, 2016) yet very few studies have considered least cost diet in feed formulations , a factor that can lower production costs of *O. niloticus*. In addition, few studies have considered economics of *O. niloticus* production using *H. illucens*. Experimenting with *H. illucens* larval in fish diets could lead to partial or complete replacement of fishmeal with *H. illucens*, lowering feed costs and in turn, lowering fish production costs. Reduced fish farming production costs will make farmed fish

to be affordable leading to the robust growth of Kenya's aquaculture industry and increased food security.

1.6 Significance of the Study

Fish feeds in Kenya are the most expensive compared to other animal feeds. The unstable fishmeal prices and its limited supply in the market significantly affect productivity of the aquaculture industry. The crude protein content of *H. illucens* larva is approximately 37 to 63 % (Barragan-Fonseca *et al.*, 2017). Therefore it can be used effectively in formulating fish feed and completely substitute fishmeal as the crude protein content in fish.

The inclusion of other cheaper ingredients will also help lower production costs and increase farmers' income and food security. Farmers could consider taking up least-cost feed formulation methods using more inexpensive available ingredients with a consideration of nutritional value in formulating a balanced diet for the fish. Essentially least cost feed formulations will enable farmers develop cost-effective diets contributing towards reducing the cost of production and increasing profitability for the sector.

The crude protein level required in *O. niloticus* diets ranges between 32 – 35 % and the daily feeding rate is approximately 3% -5% of total weight (NRC, 2011). The experiment examined the impact of utilizing *H. illucens* to produce marketable grow-out *O. niloticus*. The study can inform farmers about the reduced production cost when farmers use *H. illucens* as an alternative to fishmeal.

1.7 Scope and Limitations of the study

The study focused on the performance in growth of *O. niloticus* fed varying amounts of *H. illucens* and fishmeal. After 12 weeks of rearing male fingerlings in the JOOUST laboratory, the study examined growth performance and production costs implications of inclusion levels of *H.illucens*. Since the experiment was carried out in a controlled environment, growing fish in a lab may not accurately reflect growth indicators found in the field. A lot of the variables that influence fish growth in their natural environment are eliminated by this controlled

system.

The experimental diets used in the study with *H.illucens* as a supplement were formulated using linear programming; however, there is little information available on the subject of feed formulation using linear programming in aquaculture, which has prevented its full potential from being realized.

1.8 Operational Definition of Terms

Aquaculture – The farming of aquatic life for profit, recreation, or communal use in controlled aquatic systems.

Blue Economy - A modern concept that advances the stewardship of seas and other "blue" assets. The overarching goal is to improve human welfare and social fairness while also conserving the environment and reducing ecological scarcities.

Food Security - Implies that each individual has physical, social and financial access to sufficient, safe and nutrient dense food that meets their food choices and dietary needs for an active and healthy life at all times.

Least Cost Diet- Is an economic ratio for animal production formulated using Linear programming model. It incorporates all the highly nutritive readily available feedstuffs at a reasonable low cost to formulate a balanced diet.

Linear Programming - Linear analysis is a technique for optimizing a linear objective function and a set of linear constraints. The goal of linear programming is to find the variable values that maximize or minimize the objective function.

Production Cost - The value of all inputs used in producing output is known as the cost of production. In the case of aquaculture, inputs include seed, labor, land and capital, with the output being marketable fish.

Food Conversion Ratio (FCR) - The Feed Conversion Ratio (FCR) determines how efficiently livestock bodies convert animal feed into the desired output. The weight of the input divided by the weight of the output is the FCR.

CHAPTER TWO

LITERATURE REVIEW

2.1 Aquaculture and Food Security

Food insecurity remains a crisis in many developing countries and is more pervasive in the African and Asian continents (Baquedano 2021; FAO *et al.*, 2021). Poverty and inequality are regarded as major contributors to food insecurity because they can result in a lack of access to nutritious foods. Furthermore, climate change is viewed as a major contributor to food insecurity. Gender inequality, conflict, and displacement are all factors that contribute to food insecurity. It is critical to address the underlying causes of food insecurity while also investing in agricultural and nutritional programs that can help provide access to food.

Food insecurity has had devastating effects on the health of populations in Africa and Asia, leading to increased levels of malnutrition, decreased physical and cognitive development in children, and lower resistance to disease. In 2020, 768 million people were undernourished, with 54.4% of the global proportion of the population experiencing hunger living in Asia. A total of 282 million people encountered food insecurity in Africa, with more than 125 million people, almost 44% of the proportion of Africa's hungry people living in Eastern Africa (FAO, 2021). Food scarcity in Africa is severe due to ongoing drought, conflict, and insecurity. Food insecurity is on the rise in Asia as a result of poverty, rapid population growth, and environmental degradation (Grote, *et al.*, 2022). In addition, both regions are vulnerable to climate change, with rising temperatures having the potential to have a significant and long-term impact on food security and production. Food security can be achieved in African and Asian countries through agricultural technology, good governance, and effective resource management. To ensure that Africa and Asia increase their food productivity, favorable trade environments and pricing policies that do not harm consumers or suppliers must be established.

According to FAO *et al.* (2021), if the current trends continue, the number of undernourished people globally will rise from about 678 million in 2018 to 841 million in 2030- this estimate does not factor in the effects of the COVID-19 pandemic. In 2020, nearly a third of the

global populace (2.37 billion) could not afford adequate quantities of food, an increment of approximately 320 million people in just one year (FAO, 2021). Food distribution networks and small-scale producer trade were affected by COVID-19 pandemic movement restrictions, raising food prices for consumers and decreasing farm income.

Capture fisheries has significantly promoted food security over the years; in the recent past, aquaculture production has consistently contributed to food security, with a steady increase of 7.5% annually since 1970 (FAO, 2020). Aquaculture is on the verge of supplanting capture fisheries as the major producer of aquatic food for human consumption and it contributes significantly to global food security. In 2017, fish contributed approximately 17% of overall animal protein and 7% of all proteins consumed globally. Furthermore, fish contributed nearly 20% of the average per capita protein consumption for approximately 3.3 billion people (FAO, 2020). The low consumption of fish can be attributed to the less supply of fish globally.

In 2018, (Fig 2.2), global fish production was around 179 million tonnes. Human consumption accounted for 156 million tons, or 20.5 kilograms per capita. The remaining 22 million tons were designated for non-food uses such as the production of fishmeal and fish oil (FAO, 2020). Aquaculture accounted for 46% of total fish production and 52% of human consumption. Aquaculture is becoming a more important component of global fish production, contributing significantly to total human consumption. This is due, in part, to rising seafood demand and a decline in wild-catch fisheries, which has resulted in a greater emphasis on aquaculture production.

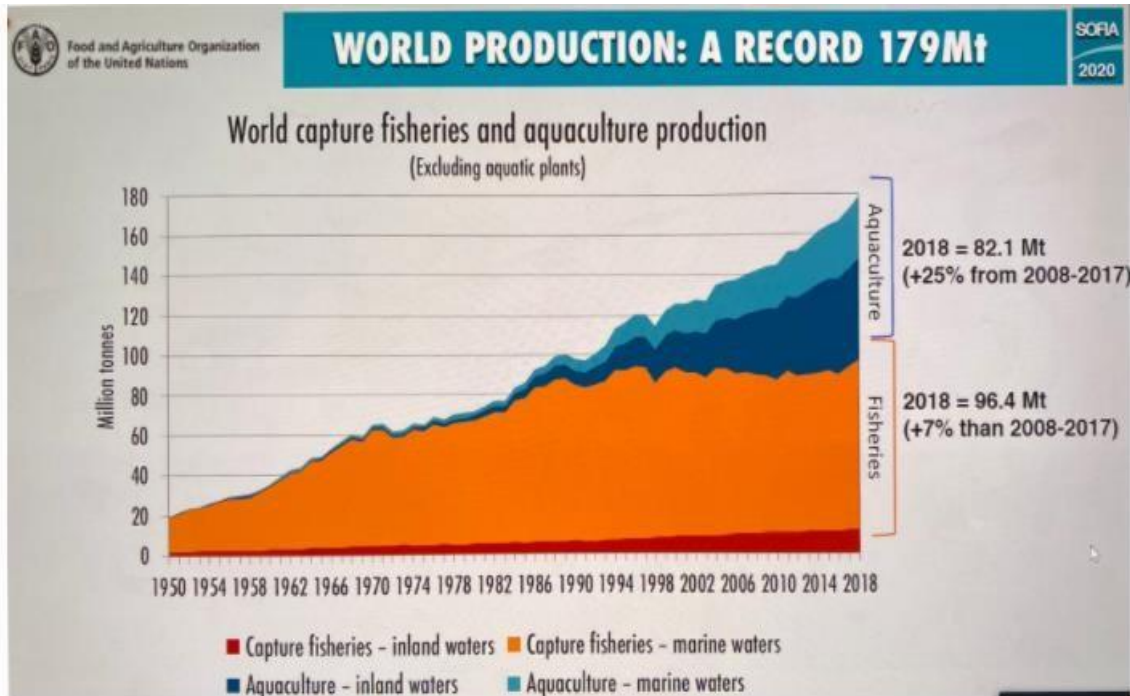


Figure 2.1: Global fisheries output, 1950-2018 (Source: FAO, 2020)

China maintained its position as a world leader in fish production, accounting for 35% of total global fish production. Despite China's leadership in fish production, per capita consumption in China was significantly lower than the global average due to the country's large population. China has a sizable aquaculture industry that accounts for a significant portion of the country's fish production. Asia (excluding China) contributed 34% of total output, followed by the US (14%), Europe (9%), Africa (7%), and Oceania (3%) (FAO, 2020). China has made significant efforts to improve the aquaculture sector, heavily investing in new technologies and improving farming practices. Through these advancements, China has maintained a high level of fish production despite its large population size.

In recent years, total fish production is increasing significantly. Aquaculture production in Africa is projected to increase by 48 %, offsetting a projected decrease in per capita fish consumption on the continent due to population growth (FAO, 2020). Aquaculture production in Africa is expected to increase due to rising demand for fish and fish products in the region, as well as the need to increase food security. Aquaculture production must also

increase to meet rising demand for fish products as wild fish stocks deplete. Aquaculture has also grown in the area as a result of the development of new technologies to improve the efficacy and efficiency of aquaculture production.

Due to its large population, Asia produces and consumes the most fish worldwide at a consumption rate of 24.1 kg per capita per year. While the average annual fish consumption in Africa is around 9.9 kg (FAO, 2020). Despite the fact that Africa consumes significantly less fish than Asia and Europe, investments in fishing and aquaculture are driving growth in African fish production.

Millions of people in developing nations depend on aquaculture as a key source of income and employment, helping to increase local food supplies and direct fish consumption. Additionally, aquaculture offers farmers a variety of sustainable sources of income and serves as a significant source of nutrition for rural communities. Kenyans consume 5kg per capita annually (Obiero *et al.*, 2019), which is only a quarter of the global average of 20.5kg per capita consumption (OECD-FAO, 2018). This discrepancy can be attributed to Kenya's lower purchasing power relative to other nations and a lack of available funds for luxuries like fish. The low fish consumption is also a result of households cutting back on their consumption due to fish's high price. Overfishing and pollution of water bodies have also reduced the availability of certain fish species (Nyamweya *et al.*, 2020). Furthermore, some Kenyan communities remain uninformed about the nutritional value of fish and other seafood.

The current global demand for aquatic food, which is 131 million tons, is expected to increase to 204 million tons by 2030 (FAO, 2020). This increase in demand is likely to put significant strain on existing aquatic ecosystems, as more fish and other aquatic creatures are caught or farmed to meet rising demand. Aquaculture will account for nearly all of this increase, as the contribution of capture fisheries to global food supplies is unlikely to increase significantly. To meet the world's rising demand for aquatic food, aquaculture production must therefore significantly increase.

2.2 Status of Kenya's Food Security and Aquaculture

The second Sustainable Development Goal aims to eliminate hunger while also improving food and nutritional security. Food and nutrition security are inextricably linked to a country's economic development. A sufficient variety of foods must be physically and financially accessible to households. Additionally, households should be able to use their resources efficiently to provide for the basic needs of all members, including food. Approximately half of Kenya's population lives below the poverty line, both in urban and rural areas (MoALF, 2017), with an estimated 13 million people undernourished between 2018 and 2020 (FAOSTAT, 2021). To address this, policies must focus on ensuring resource effectiveness and efficiency, promoting sustainable agricultural practices and systems, and incorporating food security into poverty reduction strategies.

Food insecurity was severe in urban areas in 2020 as a result of COVID-19 pandemic restrictions and containments, which disrupted the urban population's food supply and economic livelihood (FAO, 2020). Despite the government's significant achievements in combating hunger and malnutrition, enormous challenges remain. Changes in food production systems can ensure sustainable food systems while also meeting nutritional needs of high quality. Regardless of economic circumstances, sustainable food systems can provide quality, nutritious food to urban populations.

As a component of the food systems, aquaculture makes a significant contribution to food security. In Kenya, the industry has advanced. Fish farming produced 18,500 tons of fish in 2019, up 20.9% from the 15,300 tons it produced in 2018(Fig.2.2). This represented about 12.8% of Kenya's total fish output (KNBS, 2020).

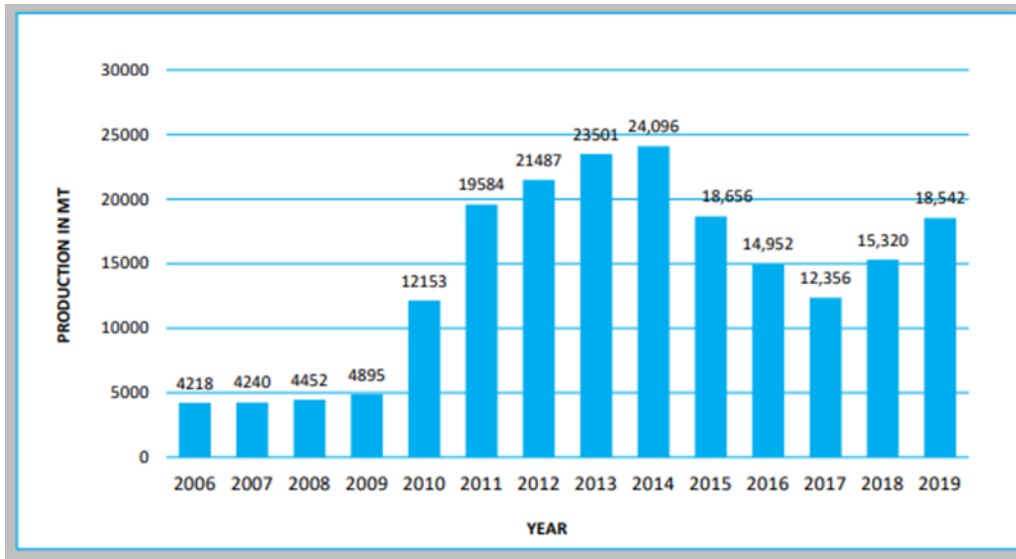


Figure 2.2: Aquaculture output in Kenya 2016-2019; source ;(FAO 2020)

By 2030, it is anticipated that the production will have increased to 150,000 metric tons (Obiero, 2019). Kenya's demand for aquaculture products has increased due to the declining capture fisheries, which has led to more investments in the industry. Increased investments in the industry have led to an increase in fish farmers and hatcheries, which has contributed to the creation of job opportunities in rural areas. Governments must therefore increase investments in aquaculture production and widen access to it for the poor by creating efficient market linkage.

Malnutrition can be decreased if more fish is consumed (World Bank, 2013). Aquaculture presents a perfect solution to sustainably increase fish supplies while addressing the issue of food security and reducing malnutrition, Aquaculture offers a special chance to enhance livelihoods and is a sustainable economic and environmental response to the world's expanding seafood demand.

The adoption of unique and modern options for water and sea-related initiatives has been heavily advocated in Kenya to attain smart, sustainable and equitable growth. Aquaculture value chain operations are part of the blue economy and they profit from greater investment prospects (Obwanga *et al.*, 2020). Making sure that the poor and undernourished have better

access to increased fish supplies and can improve their diets is essential for maximizing the nutritional benefits of aquaculture development (FAO, 2020). Governments should therefore collaborate with the private sector to foster the adoption of better aquaculture and fishing practices, invest in the development of rural infrastructure, and promote the adoption of aquaculture in order to achieve sustainability (UN, 2019).

Kenyan aquaculture is a majorly semi-intensive culture method, with ponds being the most common method of fish culture (KMFRI, 2017). Farmers have made significant investments in intensive fish farming technologies such as cage culture, recirculating culture systems and aquaponics (Veldkamp and Vernooij, 2019) increasing demand for fishmeal in aquaculture sub-sector. Of all the animal protein sources, fishmeal is the ultimate animal protein source in livestock feeds and the most common protein source in fish and shrimp feeds. However, fishmeal is quite expensive and limited in supply making its utilization in the aquaculture unsustainable. As a result, many scientists are looking into evaluating the use of insects in aquaculture as an alternative protein source.

Insects have been considered better alternative protein sources compared to protein sources of vegetable origin because they offer higher protein content, macro and micronutrients and fatty acids (Sogari *et al.*, 2019), however, their safety and health impact on fish is still under investigation (van Huis *et al.*, 2015).

Commercial feeds for *O. niloticus* in Kenya typically have a crude protein content of 24–30%. Farmers usually use locally formulated feeds because the commercial feeds are very expensive high-quality fishmeal typically has a 60 to 72 % crude protein content by weight (Miles and Chapman, 2006). Kenyan silver cyprinids, on the other hand, have a crude protein content of around 55% (Muma, 2015). Crude protein of insect species, depending on the substrate they consumes could be above the crude protein content of fishmeal, with for instance, lake flies having about (72%) crude protein (Tamale *et al.*, 2010) and field cricket containing a crude protein level of about 67.21% to 84% (Oloo *et al.*, 2020).

2.3 Benefits of Insects to the Environment

The high conversion efficiency of growing insects for food and feed is an environmental benefit. Crickets, for instance, need only 2 kilograms of feed for each kilogram of body weight gain. Rearing insects on substrates such as organic wastes aids in reducing pollution (Čičková *et al.*, 2015). Furthermore, insects produce fewer greenhouse gas emissions than farm animals, which are consistent with sustainable management; they also need very little land and water than farm animals. Insects are less likely than mammals and birds to transmit zoonotic diseases to humans, livestock and wildlife (Vantomme *et al.*, 2012) but more research is needed on this topic.

Due to the high price of fishmeal in the markets, these insects' larva could potentially substitute fishmeal as a protein source. Using insects as feed could be a very beneficial venture for farmers and feed manufacturers as the larva of some insects' species such as the *Musca domestica* or the *H. illucens* can effectively be utilized in the production of animal and aqua feeds (St-Hilaire *et al.*, 2007; Nyakeri *et al.*, 2017).

2.4 Insect Farming

In the recent past, insects have been bred in the developed world majorly for pets and zoos. The insect revolution has encouraged their consumption and use as feeds. Edible insects are primarily sourced from the wild; however, research has enabled the domestication of specific insect species due to their commercially valuable products. The most well-known examples are silkworms and bees (van Huis, 2013).

Insects today are a major source of income for many individuals and several companies have sprung in the food and feed industry (Sogari *et al.*, 2019). Since 2014, the insect products and farming enterprise has raised approximately \$124 million. Approximately \$4.2 million of the funds raised were directed toward insect-based consumer products for human consumption, with the remainder directed toward insect farming operations (Cosgrove, 2017).

In the developing world, insects are a significant source of food and income for women. Countless people in the developing world, including some of society's underprivileged members, depend on insects for a livelihood (van Huis *et al.*, 2013). Insect farming can be done on small or large-scale rearing facilities (van Huis and Oonincx 2017). Farm 432, a prototype machine developed to rear *H. illucens* larva for food, exemplifies technology used in insect farming (Skrobonja, 2020).

2.5 Insects in Fish Diets

Animal feed output must rise by 70% by 2050 to fulfill the protein demands (Steinfeld, 2012). Livestock and fish raised in ponds and cages are currently fed a combination of pasture, maize, soy, wild fish and other grains. In particular, the development of sustainable aquaculture systems must be fully exploited as the World Bank estimates that by 2030 nearly two-thirds of all seafood will be farmed, creating a feed market for aquaculture (World Bank, 2014).

Fishmeal, the primary factor in several fish feeds due to its sufficient nutritive value, is being debated as an animal feed because of its ecological, social and monetary sustainability. It's imperative to consider other sources of protein that can substitute or completely replace fishmeal in the animals' feeds. Insects have high protein, energy and fat levels (van Huis, 2013) and unlike plant ingredients, they contain taurine and hydroxyproline, both of which are lacking in plant diets (Henry *et al.*, 2015). Studies have supported the use of insects such as *H. illucens* larva, mealworm larva, adult orthoptera (grasshoppers and crickets) and silkworm pupae as feed due to their superior nutritional characteristics, ease of reproduction and biomass production. In carnivorous, omnivorous and herbivorous fish trials, insects have successfully replaced fishmeal in fish feeds. Most studies recommend replacement rates below 25-30 %. In some cases, researchers identified higher rates and even technically or economically feasible complete replacement (Tran *et al.*, 2015).

2.5.1 The Black soldier fly

The black soldier fly, *Hermetia illucens* (Linnaeus, 1758), belongs to the order Diptera, family Stratiomyidae, subfamily Hermetiinae and is found all over the world. It is distributed between 40° South and 45° North latitudes in Europe, Africa, Oceania (Australia and New Zealand) and Asia (Indonesia, Japan, Sri Lanka and the Philippines).

Often found near pig and poultry farms, where their larva can consume manure or compost and eat high quantities of organic waste, reducing odors (Newton *et al.*, 2005). Consequently, *H. illucens* larva (Fig.2.3) is a long-term solution for organic waste management. They are also efficient and environmentally friendly converters because they produce biomass rich in proteins and lipids from substrates that monogastric animals cannot eat. It has a short life cycle, of about 45 days, Eggs (4 days), Larva stage (18 days), Pupae stage (14 days), and adult stage (9 days) In the adult stage of black soldier fly, the main goal is to find a mate and lay eggs (Cannella *et al.*, 2016).



Figure.2.3: Black Soldier Fly Larva (Source; globalseafood.org)

2.5.2 Economic Importance of Black Soldier Fly Larva

The black soldier fly colonizes earthworm beds and manure basins in confined animal facilities. These flies' larvae are helpful and their existence can reduce house fly numbers by

95-100 % by out-competing house fly larva for nutrients in the waste. Furthermore, larva of black soldier flies reduces manure build up and related nutrients by 50 %. The larva are presently self-harvested and used as animal feed (Wang and Shelomi, 2017). In addition the black soldier fly frass is a valuable source of compost manure and fertilizer (Menino *et al.*, 2021). The ability to treat waste while producing a valuable product makes black soldier fly an auspicious waste management tool. It is an avenue for entrepreneurs to generate income without incurring significant investment costs while conserving the environment (Diener *et al.*, 2011).

2.6 Fishmeal

Fishmeal is an important component in the production of livestock feed. It is composed of fish or other sea creatures such as krill, shrimp, and squid. To produce a highly nutrient-dense product, the fish are typically ground up whole, including bones, scales, and heads. Fishmeal has been used in livestock diets for centuries due to its high protein content and palatability and better digestibility (Ryder and Balaban, 2011), promoting healthy growth in these animals. It also contains important nutrients like vitamins and minerals that promote overall health while providing energy for daily activities (Cho and Kim, 2011). Fishmeal is primarily obtained in Kenya from anchovies, silver cyprinid fish, and shrimp. It is widely used in aquaculture and industrial production, in addition to animal feed.

Concerns have grown in recent years about overfishing (Dahle, 2019), which deplete stocks, pollution from use of insecticides and processing operations at factories near coastal areas, where much wild caught seafood originates (Gephart and Golden, 2022). Additionally, some fishing techniques, like trawling, can be incredibly harmful to aquatic ecosystems because they drag along the ocean floor, destroying habitats and killing young fish (Daly and White, 2021). In addition due to the seasonality of fishmeal supply in Kenya, its supply in the market is usually limited increasing its price. Moreover due to increased consumer demand for fish, aquaculture has also been on the rise leading to more demand of fishmeal. Many businesses continue to rely heavily on wild caught species because they have superior nutritional qualities when compared to plant based alternatives. In response to the

challenges surrounding overfishing and the environment causing low supply of fishmeal, many businesses have started using alternative ingredients such as algae, insects, or proteins derived from bacteria in order to create sustainable fishmeal.

The black soldier fly larvae meal stands out as an alternative protein source because it is high in protein. BSF larvae also contain essential fatty acids, which are required for healthy growth and development in fish (English *et al.*, 2021). They have a higher nutritional value than traditional fish meal products; for example, *Rastrineobola argentea* (silver cyprinid fish) contains approximately 40% crude protein (Veldkamp and Vernooij, 2019), whereas BSF crude protein levels typically range from 28 to 48% and lipid levels range from 12 to 42% (Barragan-Fonseca *et al.*, 2017). They can convert organic waste into nutrient-dense food with minimal environmental impact. Furthermore, because they require less water and land, BSF are more environmentally friendly aquaculture alternatives.

Due to its high protein content and additional vitamins and minerals, fishmeal continues to be a valuable source of nutrition for fish; however, alternative protein sources must be taken into account to ensure the sustainability of the aquaculture industry.

2.7 The Nile Tilapia

The Nile tilapia (*Oreochromis niloticus* L.1758) (Fig. 2.4) is a shallow-water tropical species. It is the most widely cultivated and consumed fish on the planet (Mjoun, *et al.*, 2010). Temperatures between 31°C and 36°C are preferable for *O. niloticus* growth, with minimum and maximum survival temperatures of 11-12°C and 42°C, respectively. It is an omnivorous species (Obiero *et al.*, 2019) which feeds on periphyton, aquatic plants, small invertebrates, phytoplankton benthic fauna, debris and detritus (FAO, 2009).



Figure 2.4: Nile Tilapia (*Oreochromis niloticus*) (Source; Biovision)

The female tilapia reaches sexual maturity in five to six months (Bhatta *et al.*, 2012). At 24°C, spawning begins through the breeding process, in which an area, consisting of a dug crater like spawning nest, is developed and protected. After the ripe female spawns in the nest, the male fertilizes the eggs. The female then gathers the eggs in her mouth, broods and incubates them in her mouth. Incubating and brooding times usually takes one to two weeks depending on variations in temperature. The female consumes little or nothing while brooding. *O.niloticus* can live for more than ten years, exceeding five kilograms of weight (Mjoun *et al.*, 2010).

2.7.1 Nutritional Requirements of *O. niloticus*

The Nile tilapia (*Oreochromis niloticus*) is a freshwater cichlid with omnivorous and herbivore tendencies. It mainly consumes phytoplankton, macrophytes, insects, wastes, zooplankton algae and plant material (NRC, 2011). In addition, it is highly resistant to severe environmental conditions, consumes both formulated diets and natural foods, making it economically viable.

Tilapia should feed on a completely balanced diet that includes an adequate supply of protein, lipids, carbohydrates, vitamins and minerals to achieve optimal growth. Farmers

often find commercial feeds prohibitively expensive, so they turn to manures and agricultural byproducts to cut production costs. Most developing-world fish farmers have relied heavily on manures and tilapia by-products due to lack of prepared feeds (FAO, 2009).

The protein content on commercial feeds is usually around 32-36%. *O. niloticus* should consume approximately 3-5% of their total body weight. Fingerlings can be fed on the second day after putting them in the pond and should be majorly fed on powder food. The pellet size can be adjusted based on the fish growth rate and fish size. The feeding rate depends on the tilapia consumption of food (NRC, 2011).

2.7.1.1 Protein and Energy Requirement of *O. niloticus*

Proteins are made up of amino acids that are connected by peptide bonds. Fish diets must contain all of the essential amino acids for optimal growth. A lack of essential amino acids in fish feed slows growth, reduces weight gain and feed efficiency and impairs disease resistance. Arginine, Histidine, Isoleucine, Leucine, Methionine, Phenylalanine, Threonine, Tryptophan and Lysine are essential amino acids for Nile Tilapia (Lall and Dumas, 2015; NRC, 2011). Protein requirements for Nile tilapia vary depending on the source of protein in the diet, the size and age of the fish (Table 2.1) and the diet's energy level. First-feeding larva require 45-50 % crude protein, 35-40 % for fry and fingerlings (0.02-10 grams), 30- 35 % for juveniles (10.0-25.0 grams) and 28-30 % for on-growing larva of 25 grams or more (El-Sayed, 2013; Muteti *et al.*, 2020). Protein and fat provide more energy to most fish than carbohydrates (Bernadate *et al.*, 2020). The optimal protein to energy ratio in the diet for fry and fingerlings is estimated to be 110 to 120 mg of digestible energy per kilocalorie respectively (FAO, 2021).

Protein digestibility is optimal at 25°C and the best dietary protein to energy ratio for fry and fingerling is approximately 110 to 120 mg per kcal digestible energy. The tilapia brood fish requires 40- 45 % protein for maximum reproduction, larval growth and survival (Mjoun, *et al.*, 2010).

Table 2.1 Protein and Energy Requirements for *O. niloticus*

Life Stage	Weight	Requirement (%)
First Feeding Larva		45-50
Fry	0.02 -1.0	40
Fingerlings	1.0 -10.0	35-40
Juveniles	10.0 -25.0	30 – 35
Adults	25-200	30-32
	> 200	28-30
Brood Stock		40-45
Protein/Energy ratio mg/kcal	0 .02-10.0	110-120 mg/kcal

Source: (FAO, 2021)

2.7.1.2 Lipid Requirement

Lipids (fats) are energy-rich nutrients that can replace proteins in aquaculture diets (Craig *et al.*, 2017). They are carriers for fat-soluble vitamins A, D, E, K and other nutrients (Lim *et al.*, 2011). Reducing protein requirements from 32.2 to 25.7 % can be done by raising levels of dietary lipids from 5.7 to 9.4 % and increasing carbohydrates levels from 31.9 to 36.9. *O. niloticus* cannot tolerate high lipid levels in its diet. A lipid level of more than 12% inhibited the growth of *O.niloticus* hybrids while increasing carcass lipid accumulation (Lim *et al.*, 2011). The minimal dietary fat necessary for *O. niloticus* is 5%, but studies show that diets containing 10-15% fat improve growth and protein utilization. The polyunsaturated fatty acids (PUFA) n-3 and n-6 are critical for optimal hybrid tilapia (*O.niloticus*) growth and development (Bernadate *et al.*, 2020; FAO, 2021).

2.7.1.3 Carbohydrate

Carbohydrates are cheap energy source for the *O.niloticus* and conserve a lot of protein for growth rather than energy. Carbohydrates sources increase feed palatability, lower dust content in finished feeds and reserve a large amount of protein for growth rather than providing energy (NRC, 2011). Carbohydrate sources, other nutritive factors, fish species and feeding frequency are factors that influence *O. niloticus* carbohydrate utilization. *O. niloticus* can consume large amounts of carbohydrates, with almost 30 to 70% of their diet consisting of carbohydrates (FAO, 2021).

Minimal research has been done on carbohydrate requirements for optimal growth of *O. niloticus*. Therefore, more research is required in this area so as to determine the maximum dietary carbohydrates that *O. niloticus* can utilize. In addition, studies focusing on analyzing effects of increasing carbohydrate levels in Nile tilapia on growth and production costs will contribute towards reducing protein costs hence reduced costs of production.

2.7.1.4 Vitamin and Minerals

Minerals and vitamins are required for tilapia bone formation and act as enzyme co-factors in various metabolic processes. They help maintain the blood's acid-base balance, transmit nerve impulses and support the formation of metalloproteinase like haemoglobin. They are required for the synthesis of defense cells, the integrity of the skin, gills and intestinal mucosa, as well as the promotion of healing (Kubitza, 2019).

Minerals and vitamins have antioxidant properties and help to regulate fish immunity. Oversupply of certain minerals causes deficiencies in other minerals and in extreme circumstances, can be harmful to fish (Pierri *et al.*, 2021). For instance, high calcium content in the diet can lead to deficiencies of phosphorus, zinc, iron and manganese and high quantities of zinc, copper and selenium in fish diets can be toxic to a variety of fish (Mjoun, *et al.*, 2010).

Vitamins are either water-soluble or fat-soluble. Fish usually requires minute quantities of eight water-soluble vitamins. Thiamine, riboflavin, niacin, vitamin B6 (pyridoxine, pyridoxal and pyridoxamine), folic acid, vitamin B12, biotin and pantothenic acid are all water soluble vitamins. These vitamins, known collectively as vitamin B complex, primarily serve as co-enzymes. Choline, inositol and vitamin C are three water-soluble vitamins that are in high demand and serve different functions than coenzymes. Vitamin E and B6 requirements of tilapias are linked to lipid and protein levels in the diet. For maximum growth, *O. niloticus* diets should contain about 5 and 12 % lipid and should have about 42-44 and 60-66 mg vitamin E/kg respectively. When fed diets containing 28 and 36 % protein, *O. niloticus* requires 1.7 - 9.5 and 15.0-16.5 mg vitamin B6/kg diet, respectively (Shiau and Lin, 2006).

O. niloticus require higher levels of macro minerals such as calcium, chlorine, magnesium, phosphorus, potassium and sodium. Micro minerals are included in much lower amounts in the diet. The most well-known trace minerals are chromium, copper, iodine, iron, manganese, selenium and zinc (NRC, 2011). The element selenium, which has been linked to fish health, is currently of particular interest. A lack of selenium in fish can decrease immunity and increase mortality (Farzad *et al.*, 2019).

2.8 Fish Feed Formulation Guidelines

Fish require a sufficient amount of protein, lipids, energy, vitamins and minerals. The correct feeding method and appropriate feeding contribute enormously to growth performance. To maximize production efficiency, fish producers should carefully consider management practices, disease management and stock choices, in addition to proper food and nutrition (DeSilva *et al.*, 1991). Table 2.2 shows the guidelines for *O. niloticus* feed specifications and feeding rates.

Table 2.2: Feeding rates based on the fish weight and culture system

Feeding Size	Feeding Size	Particle Feeding rate(% of body weight)		Feeding Frequency No of days
		Semi-intensive (<20,000/ha)	Intensive(>2000 ha)	
<1	<0.5	30-10	-	To satiation
1 to 5	0.5-1	10 to 6	-	6
5 to 20	1 to 2	6 to 4	-	4
20-100	3.2	4 to 3	-	4
100-250	3.2-4.6	3	-	3
250-500	4.6	3 to 2	2.0-1.5	3
>500	4.6	2-1.5	1.5-1.3	3-2

Source :(Miao and Liang 2007)

2.8.1 Feed Conversion Ratio

According to KMFRI (2017), feeding costs account for roughly 70% of total fish production costs. As a result, the rate at which *O. niloticus* convert feed to body mass may be the most important factor in determining profitability. The feed conversion ratio (FCR) measures how well an animal converts feed to body mass. It is calculated by dividing the weight of feed fed by the increase in live body weight over a specified time period.

Tank-grown *O. niloticus* can have very efficient feed conversion ratios depending on feed management practices. Feed conversion ratio is one of the most important benchmarks for measuring operational efficiency in tilapia production. However, FCR alone does not truly measure yield. To ensure that the bi-weekly growth target is reached, estimates are made based on initial and final fry biomass weights. The total amount of feed required for that week is calculated based on the required growth rate and the realistic FCR ratio set. An artificially low FCR can be created by underfeeding, so it is important to consider the growth rate also. The feed conversion ratio is essential for budgeting (USAID, 2011).

2.9 Theoretical Framework

2.9.1 Production Cost Theory

The cost of production theory is the basis of this study, with an assumption that aquaculture firms aim to increase their profits at the least possible cost. Production functions help predict how the enterprise is able to convert output with a certain level of input. Output level can be forecasted based on inputs used in the enterprise (Pindyck and Rubinfeld, 2013). The Cobb-Douglas production function forms the major basis of the study with the production function illustrated as; $y = f(x_1, x_2, x_3, x_4)$. Indicating that y denotes the revenue from the fish produced and x_1, x_2, x_3 and x_4 refer to the inputs used.

Production costs are classified as fixed and variable factors in the short-run. When combined in variable proportions, the law of variable proportions is considered. When the level of inputs increases the cost incurred also increases. Therefore, this law is also known as law of

increasing costs. The linear, quadratic, log-linear (Cobb-Douglas, C-D), function in the aquaculture production requires certain inputs to maximize the profit. The inputs include land, seed, feed, hired labor and capital while the output is the marketable fish or seed. The inputs are either variable or fixed costs. Although many inputs are used in most production processes, normally costs are categorized into: capital and labor (Pindyck and Rubinfeld, 2013). Before investing in the aquaculture industry, many external factors must be carefully considered. External factors such as sourcing inputs and market protection pose business risks. As a result, producers must accurately calculate costs before making sound decisions.

2.9.2 Production Costs of Nile tilapia (*Oreochromis niloticus*)

Economic feasibility of an aquaculture venture is based on production at competitive cost and ability of the product to be sold at a profitable price relative to other animal-protein sources. Reducing production cost in aquaculture contributes to more profits.

Aquaculture production costs primarily cover the following items: chemicals (disease control, fertilizer), seeds (eggs, fry), feed, labor, water pumps, heating, oxygenation, fuel (operation and transportation), harvesting equipment (nets, elevators, tractors), labor and transportation facilities (Obwanga *et al.*, 2020). Feed costs account for about 70% of all variable costs (KMFRI, 2017) and farmers increasingly use low-quality alternative feed. Some combine commercial feed with kitchen and restaurant waste and chicken by-products, while others use cheap chicken and duck feed instead of tilapia feed compromising growth of fish.

2.9.3 Least Cost Feed Formulation in Aquaculture

Linear programming feed formulation incorporates the assumption of a linear relationship between animal performance and the nutrients contained in the feed. The linear programming model includes mathematical models that reduce feeding costs while optimizing the nutrient content needed for the fish and solving using mathematical techniques (Ghosh, 2003; Porchelvi *et al.*, 2018). Feed manufacturers and farmers who apply the linear programming method reduce the cost of feed and maximize output.

When developing the least cost feed, nutritionists consider the optimal proportions of diverse feed ingredients that meet the necessary nutritional needs of protein, fat, carbohydrates, fibre, essential amino acids, calcium phosphorus and digestible energy for a given fish species. The overall cost per unit of the formulated feed is the feasible minimum cost. The linear programming model allows one to set multiple restrictions, maximum or minimum nutritional requirements and ingredient inclusion based on price and nutritional value (Ghosh 2003; Porchelvi *et al.*, 2018).

Minimizing feed cost in aquaculture which contributes about 70% to the production cost in aquaculture (KMFRI, 2017) can be done by reducing the price of a kilogram of the diets and using alternative feed ingredients. More than 50% of the on-farm feeds prepared by farmers in Kenya are formulated through the trial and error method or the simple Pearson square method (Muteti *et al.*, 2020). The on farm feeds do not satisfy the dietary needs for *O. niloticus*, causing declined growth and reducing profits in this sector.

Currently, there are several programs developed that incorporate linear programming for feed formulation. Win feed is one of the programs. However, win-feed is usually too expensive to install for local farmers and may not be quite expensive; farmers may not easily understand its interfaces; hence may not be entirely beneficial to them. In this case, farmers could consider the ready to use excel linear programming option since it's readily available after installation and easier to use. To economically produce healthy products at reasonable prices fish feeds must adequately meet dietary needs of fish.

2.10 Conceptual Framework

In ensuring sustainable food security, insects' potential particularly, the *H. illucens* larva in sustainably supplying the aquaculture sector with alternative feed is massive. Sustainable production of low-cost feeds for *O. niloticus* using *H. illucens* larva can increase growth performance in fish. Furthermore, the *H. illucens* larva meal being an inexpensive source of protein will help reduce the cost of production for the aquaculture sector as feeds contribute

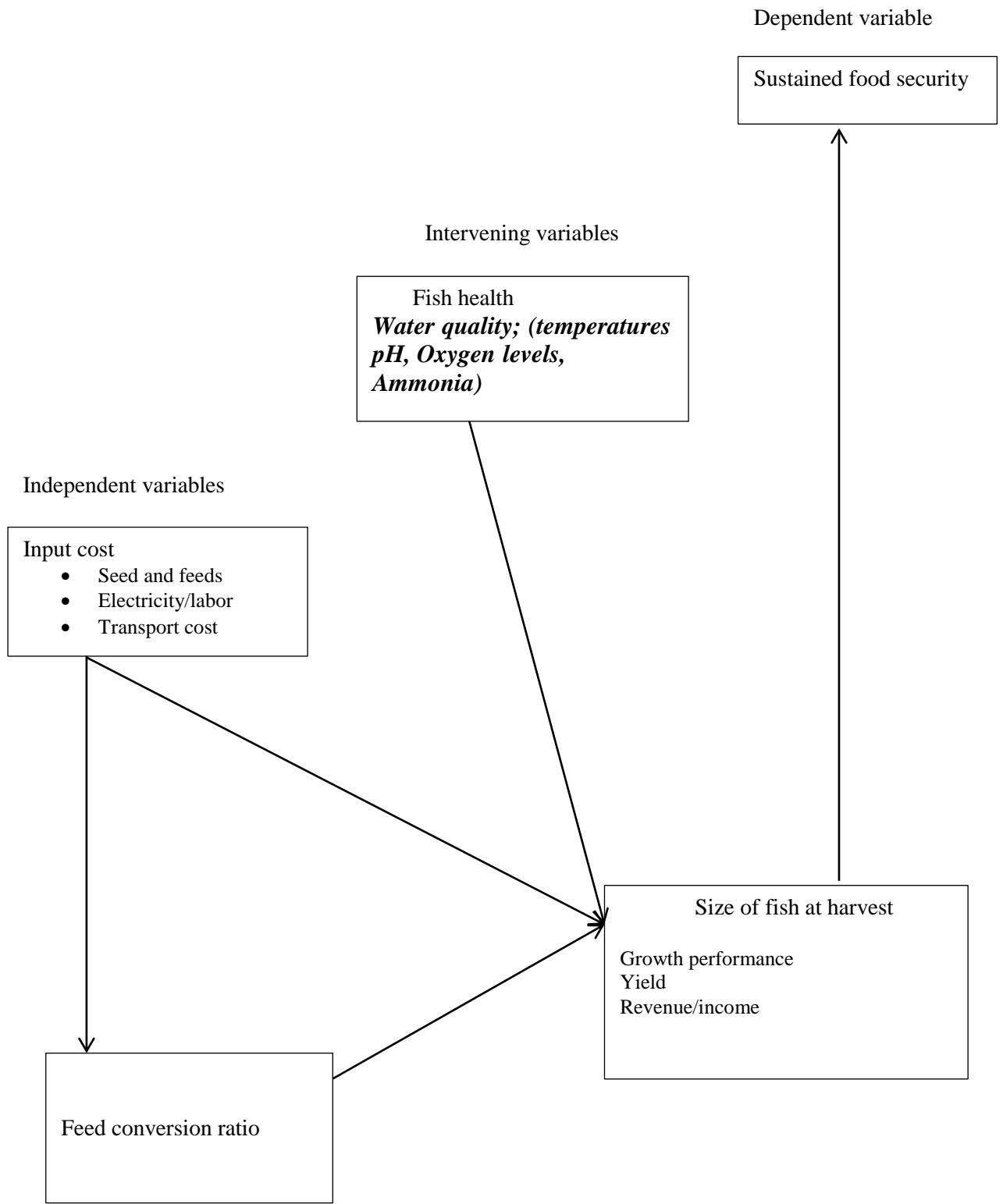
significant costs in aquaculture.

For the sustained food security and the for the aquaculture sector to thrive, the sector must adapt the use of low-cost diets and use feed formulation technologies to reduce feed cost. For instance, the use of the least cost feed formulation will help farmers be critical of the cost of ingredients and the total cost of feeds hence invariably reducing input costs on fish feeds. Using insects such as *H. illucens* larva will also aid farmers to understand how they can learn to produce their own protein sources ultimately reducing the cost of protein source and saving on the cost of silver cyprinid fish that is quite expensive sometimes unavailable.

The explanatory variables in this study were the input cost on feed, the seed cost, electricity and hired labor. In contrast, the intervening variables are the water quality parameters (oxygen, pH, temperatures), affecting the fish growth rate and fish health. The dependent variable is yield and rate of returns to farmers, whereby high input cost affects the level of returns and water quality parameters will also affect the total yields of the fish. Farmers should also observe intervening variables such as water quality to ensure that fish is not strained and in good health; hence, monitoring oxygen supply, temperatures and pH to understand the delayed fish growth. Once they understand how water quality parameters affect growth, they can enhance these conditions to increase productivity.

In addition, feeding rate, mono sex culture and protein inclusion according to their body weight and age in months must be observed to ensure that the growth cycle is reduced. In this study, the conceptual framework illustrates how these variables interact and influence the aquaculture sector and how they contribute to food security.

Figure 2.1 Conceptual Framework



CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Location

The study was conducted at Jaramogi Oginga Odinga University of Science and Technology (JOOUST), located in Bondo town, Siaya County Kenya. The University is located at the following geographical coordinates 0.0926° S, 34.2587° E. The sub-county's climate is influenced by the effect of Lake Victoria, it also experiences equatorial climate, affecting rainfall distribution.

3.2 Diet Formulation

The *H. illucens* larva meal was obtained from the JOOUST insect farm, while other ingredients including soybean meal, wheat bran, wheat pollard, fishmeal and vitamin premix were obtained locally from the market.

Proximate analysis for *H.illucens* , fishmeal and formulated diets was conducted according to the procedures of AOAC, (1995) .In formulating the diets the nutritional content for the other feed ingredients were obtained from feed tables. For this study the *H.illucens* larvae were sundried mildly before diet formulation. The feed ingredients including *H. illucens* were ground into fine powder using a commercial feed mill before being subjected to proximate analysis and diet formulation. Before formulating the diets, a database with all the current feed ingredients used in fish feed formulation with their nutritional values was developed and computed using the linear programming excel solver.

Five isonitrogenous approximately (30%) and isocaloric approximately 18 ME/Kg/DM test diets were formulated using excel solver linear programming model (Table 3.5). The diets were formulated with ingredients such as *H.illucens* larva meal (BSF), soya bean meal, maize, wheat pollard, wheat bran, sunflower meal, sunflower oil, fishmeal, salt, di-calcium phosphate (DCP) and vitamin premixes. The diets were ground and hand mixed then pelleted using standard commercial screen sizes of 2mm, after which they were cooled and packaged. Pelleting of

formulated fishmeal diets was done at Great Lakes Feed Company in Bondo. Proximate analysis of the formulated diets was then conducted. Table 3.1 shows the prices of feed ingredients and their nutritional composition.

Table 3.1 Nutritional composition and prices of the feed ingredients

#	Ingredients	Protein %	Lipid %	Energy %	Carb %	Ash %	Fibre %	Cost in Ksh kg ⁻¹
1	BSF	41.70	41.00	23.70	0.80	4.60	8.64	85
2	Maize	7.60	3.60	16.10	63.8	1.20	2.30	100
3	Soya Bean Meal	36.00	18.40	20.80	5.30	5.10	5.60	65
4	Wheat Pollard	15.70	4.20	16.80	31.2	3.90	7.00	25
5	Wheat Bran	15.30	3.30	16.40	19.4	4.80	9.20	25
6	Sun flower Meal	32.40	2.20	19.40	6.10	7.10	27.90	30
7	Sunflower Oil	0.00	99.00	16.40	0.00	0.05	0.00	110
8	Fishmeal	63.50	14.50	18.60	0.00	15.20	0.27	200
9	Salt	0.00	0.00	0.00	0.00	0.00	0.00	30
10	DCP	0.00	0.00	0.00	0.00	89.50	0.00	80
11	Vitamin Premix	13.50	3.90	15.80	0.00	5.30	3.00	250

The Linear programming model used to formulate the diets

The mathematical model is expressed as shown below; where the objective of the model is to minimize the total cost of feed ingredient used to formulate feed.

The Linear Programming Model

Notations

$$\text{Min } Z = \sum_{i=1}^r C_i x_i$$

Where Z is the sum of total cost of feeds used in formulating the diets , X_i are the decision variables

Subject to;

$$\sum_{i=1}^r x_i = M(\text{Demand Requirement})$$

$$\sum_{i=1}^r a_{ki} b_k \geq b_k(\text{Minimum Requirement})$$

$$\sum_i^r = 1 a_{ki}x_i \leq b_k \text{(Maximum Requirement)}$$

$$\sum_i^r = 1 a_{ki}x_i = b_k \text{(Restricted Constraints)}$$

Let

- k = Ingredient nutrient elements k= 1, 2... r
- i = Ingredient composition components i = 1, 2..., j
- x_i = Ingredients quantities i in the feed mixture
- C_i = Ingredient i Unit cost
- M = Weight (kg) of formulated feed
- Z = Total feed ingredients cost
- a_{ki} = Quantity of nutrient n in feed ingredient i.
- b_k = Nutrient requirement n for the fish specie

The mathematical model is expressed as shown below; where the objective of the model is to minimize the total cost of feed ingredients used to formulate feed:

Let $i_1, i_2, i_3, i_4, i_5, i_6, i_7, i_8, i_9, i_{10}, i_{11}$ be the corresponding amounts in kg of fish meal, BSF, soybean meal, wheat bran, wheat pollard, maize, sunflower oil, vitamin premix, salt, and di-calcium phosphate required to formulate the diet.

$$i_1 = \text{BSF}$$

$$i_2 = \text{Maize}$$

$$i_3 = \text{Soya Bean Meal (SBM)}$$

$$i_4 = \text{Wheat Pollard}$$

$$i_5 = \text{Wheat Bran}$$

$$i_6 = \text{Sunflower Meal}$$

$$i_7 = \text{Sunflower oil}$$

$$i_8 = \text{Fish Meal}$$

$$i_9 = \text{Salt}$$

$$i_{10} = \text{Dicalcium Phosphate}$$

$$i_{11} = \text{Vitamin Premix}$$

Model Formulation

The problem was to determine the quantities of the 11 feed ingredients so that the nutritional requirements of *O.niloticus* were met. Based on this information, a linear programming model was formed as follows;

Total weight of the feed to be formulated = 100kg

Crude Protein \geq 30kg

Ash \geq 0.5kg

Carbohydrate \geq 36kg

Fibre \geq 9kg

Lipid \geq 9kg

Energy \geq 18MJ ME/kg

Minimize z

Minimize $Z = 85x_1 + 100x_2 + 65x_3 + 25x_4 + 25x_5 + 30x_6 + 110x_7 + 200x_8 + 30x_9 + 80x_{10} + 250x_{11}$

The objective was to minimize cost Z, illustrated above, subject to the constraints shown below and computation by Solver module of MS-excel;

Subject to:

Constraint 1; $0.417x_1 + 0.076x_2 + 0.36x_3 + 0.157x_4 + 0.153x_5 + 0.324x_6 + 0.635x_7 + 0.0135x_8 \geq 30$; (Protein Requirement)

Constraint 2; $0.41x_1 + 0.036x_2 + 0.184x_3 + 0.042x_4 + 0.033x_5 + 0.022x_6 + 0.99x_7 + 0.095x_8 + 0.039x_9 \geq 9$; (Lipid Requirement)

Constraint 3; $0.237x_1 + 0.061x_2 + 0.208x_3 + 0.164x_4 + 0.168x_5 + 0.186x_6 + 0.194x_7 + 0.164x_8 + 0.158x_9 \geq 18$; (Gross energy Requirement)

Constraint 4; $0.008x_1 + 0.638x_2 + 0.053x_4 + 0.312x_5 + 0.194x_6 + 0.061x_7 \geq 36$; (Carbohydrate Requirement)

Constraint 5; $0.107x_1 + 0.012x_2 + 0.051x_3 + 0.039x_4 + 0.048x_5 + 0.071x_6 + 0.0005x_7 + 0.178x_8 + 0.895x_9 + 0.053x_{10} \geq 0.5$; (Ash Requirement)

Constraint 6; $0.087x_1 + 0.023x_2 + 0.056x_3 + 0.007x_4 + 0.092x_6 + 0.279x_7 + 0.03x_8 \geq 9$; (Fibre Requirement)

Constraint 7; $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} = 100$ (Demand Requirement)

Linear programming was used to formulate the diets, based on the price of feed ingredient per kilogram, the *Oreochromis niloticus* diet's nutrient requirement, and the compounded feed's total weight. The model considered the cost of ingredients, the nutritional requirement constraints for each feed and the objective functions as illustrated below.

Table 3.2; Minimum and Maximum Inclusion Levels of Ingredients the Linear Programming Model

#	Ingredients	Protein %	Lipid %	Energy %	Carb %	Ash %	Fibre %	Cost in Ksh kg ⁻¹
1	BSFM	37.7	32.6	23.7	0.8	10.7	8.7	85
2	Maize	7.6	3.6	16.1	63.8	1.2	2.3	100
3	Soya Bean Meal	36.0	18.4	20.8	5.3	5.1	5.6	65
4	Wheat Pollard	15.7	4.2	16.8	31.2	3.9	7.0	25
5	Wheat Bran	15.3	3.3	16.4	19.4	4.8	9.2	25
6	Sun flower Meal	32.4	2.2	19.4	6.1	7.1	27.9	30
7	Sunflower Oil	0.0	99.0	16.4	0.0	0.05	0.0	110
8	Fish Meal	62.6	9.5	18.6	0.0	17.8	0.0	200
9	Salt	0.0	0.0	0.0	0.0	0.0	0.0	30
10	DCP	0.0	0.0	0.0	0.0	89.5	0.0	80
11	Vitamin Premix	13.5	3.9	15.8	0.0	5.3	3.0	250
	Minimum Inclusion	30.0	5.0	14.3	25.0	5.0		
	Maximum Inclusion	35.0	15.0		40.0		5.0	

BSF- Black soldier fly larvae meal, SBM-Soya Bean Meal, DCP- Dicalcium Phosphate,
Min-Minimum inclusion level, Max-Maximum Inclusion level

Fishmeal and *H. illucens* larva (BSF) were supplemented at different percentages in the diets (FM 0%, BSF₂ 25%, BSF₃ 50%, BSF₄ 75% and BSF₅ 100%). Other ingredients were also included. Feed was formulated as shown in (Table 3.5).

Table 3.4: Inclusion levels of feed ingredients in *O.niloticus* diets

Ingredients	FM	BSF ₂	BSF ₃	BSF ₄	BSF ₅
%Inclusion	0%	25%	50%	75%	100%
BSF	0.00	4.15	8.30	12.45	16.60
Maize	10.00	10.00	10.00	10.00	10.00
Soya meal	33.50	33.50	33.50	33.50	33.50
Wheat bran	14.00	14.00	14.00	14.00	14.00
Wheat pollard	20.00	20.00	20.00	20.00	20.00
Sunflower cake	5.00	5.00	5.00	5.00	5.00
Sunflower oil	0.10	0.10	0.10	0.10	0.10
Fishmeal	16.60	12.45	8.30	4.15	0.00
Di-calcium phosphate	0.10	0.10	0.10	0.10	0.10
Rock salt	0.20	0.20	0.20	0.20	0.20
Vitamin premix	0.50	0.50	0.50	0.50	0.50

The linear programming tool formulated the diets as shown below (Table 3.5) with supplementation levels of *H.illucens*

Table 3.5: Nutritional composition and cost of the formulated fish diets

Treatment	Cost of formulated Diet(KES)	Nutritional composition				
		CP %	EE %	CF%	ME/ Kg/DM	Ash
FM	71.23	31.53	4.98	5.98	17.95	6.72
BSF ₂	66.45	30.32	6.08	6.35	18.16	6.29
BSF ₃	61.68	31.41	7.91	6.71	18.37	5.85
BSF ₄	56.91	30.51	8.29	7.07	18.59	5.41
BSF ₅	52.14	29.60	9.39	7.42	18.90	4.97

DM- Dry matter, CP- Crude protein, EE-ether extracts, CF -crude fibre, ME- Metabolizable Energy Kg⁻¹DM- dry matter

3.3 Experimental Design

Mono sex male *O. niloticus* fingerlings weighing about 15 ± 0.06 grams were obtained from Lake Agro Limited in Siaya. The initial 14 days were allowed for acclimatizing the fingerlings to laboratory conditions. The study was conducted over a 12-week period at the JOOUST laboratory.

The experiment employed completely randomized designed (CRD) with five treatments; FM (Control), BSF₂, 25%, BSF₃, 50% BSF₄, 75% and BSF₅, 100%). The treatments had a crude protein content of 29-30%. Each treatment was replicated three times. The research work was undertaken in 90 litres rectangular glass aquaria of dimension 70 x 35 x 40cm each, each aquarium containing 15 fingerlings (Plate 3.1). One fish per 2 litres stocking density was used per aquarium.

Fingerlings were fed experimental diets three times a day, at three-hour intervals from morning to evening throughout the study. The feed were given at 3% of their body weight daily. On each feeding schedule, the daily feed ratio was divided equally amongst all treatments.



Plate 3.1: The experimental set up conducted in triplicate for 12 weeks

3.3.1 Data Collection Procedure

Data was collected on temperature, water quality, ammonia, pH, growth performance (weight and length) parameters and production cost. During the experiment water quality parameters were frequently monitored to provide suitable conditions for optimal fish growth performance. Fish were collected from each aquarium using a plastic filter basket and weighed to the nearest 0.01g using a digital weighing balance. A fish measuring board was used to measure lengths (cm). The values (length and weight) were used to calculate the mean biweekly growth. The biweekly data was utilized to calculate the specific growth rate mean weight gain and length gain. Daily mortality rates were recorded. At the conclusion of the experiment, weight and length data were used to calculate growth performance measures such as final mean weight, mean weight gain, specific growth rate, feed conversion ratio, survival rate, and Economic feed conversion ratio.

During the experiment, an adequate dissolved oxygen level was maintained through aeration using aquarium bubbler. The experimental tank water temperature, pH and dissolved oxygen (DO) were measured three times daily, at 9:00 a.m., 1:00 p.m. and 4:00 p.m. and recorded in a water quality parameter worksheet. Dissolved oxygen was measured using an oxygen meter (Yellow Springs, YSI 550A U.S.A). Temperature and pH were measured using an electronic pH probe.



Plate 3.2: Photo of water quality instruments: a, Oxygen meter and b, Electronic pH probe

3.3.2 Sampling Procedure

All fish in the aquaria were sampled fortnightly. During the study period, the weight and length of all fish in each aquarium were measured. A fish measuring board was used to determine the length (cm), while a top-loading balance was used to determine weight (g). The difference between the initial and final weights was recorded for the entire study period. The specific growth rate (SGR), food conversion ratio (FCR), length-weight relationship and condition indices were generated using these parameters.

3.4 Analysis of Growth parameters

The performance of the fingerlings' growth was measured biweekly based on weight, length, weight gain and length gain. Specific growth rate (SGR) is the variation in fish weight measured as increment in body weight as a percentage daily in a particular period. It was estimated using body weight natural logarithms and expressed as daily growth rate as a percentage (Ricker, 1979)

$$\text{i) SGR \%/day} = \frac{[(\ln \text{FW} - \ln \text{IW}) \times 100]}{\text{n days}}$$

Where FW refers to the final body weight (g) and IW, the initial body weight (g) and "n days" denotes the total experimental period in days. Ln denotes natural logarithm.

$$\text{ii) Weight Gain} = \text{Final Weight (g)} - \text{Initial Weight (g)}$$

$$\text{iii) Weight gain (\%)} = \frac{(\text{Final weight} - \text{Initial weight}) \times 100}{\text{Initial weight}}$$

$$\text{iv) Survival \%} = \frac{\text{Final fish number} \times 100}{\text{Initial fish number}}$$

3.4.1 Feed Conversion Ratio (FCR)

For each treatment, the feed conversion ratio was calculated by dividing the amount of feed consumed by the weight gain using the formula;

i) $FCR = \text{Total weight of feed given (g)} \div \text{Weight (g)}$

ii) $\text{Economic feed conversion ratio (eFCR)} = \frac{\text{Total cost of feed fed (g)/t}}{\text{Total value of wet weight gain (g)}}$

3.4.2 Length-weight relationship

Linear regression analysis was used to determine the length-weight (log-transformed) relationships and length-weight scatter diagrams were plotted. The length-weight relationship of the fish was calculated using the cube law (Cren, 1951).

i) $W = aL^b$

Where, W=fish weight (g), L= Total length (cm), a=regression intercept and b=regression slope. The logarithmic transformation for the formula is;

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

When the values of 'b' equal 3, the growth is classified as isometric; otherwise, it is classified as allometric.

ii) $\text{Fulton's Condition factor (K)} = \frac{100W}{L^3}$ determined the health index of the fish

$$K = 100 \frac{W}{L^b}$$

Where, K = Condition factor, L = Total length of fish in centimeters (cm), b = Regression Co-efficient obtained from length-weight equation.

3.5 Ethical considerations

The research sought the approval of Ethical Review Committee (ERC), JOOUST Postgraduate School and National Commission for Science, Technology and Innovation (NACOSTI) before the beginning of the study. The study also considered ethical guidelines put in place for use of fish in experimental designs (NRC, 2011; Sloman *et al.*, 2019). Healthy fish stocks were starved a day prior their transportation to the JOOUST lab. Fish were transported in oxygenated fish bags the next day early morning to curb stress to the fish. The lab water used in the aquaria was left to stand for two days to dechlorinate before use in the glass aquaria. During the study period, the welfare of the experimental fish was maintained by ensuring that the fish were not stressed and they were healthy.

3.6 Statistical Analysis

Data for all parameters were collected and recorded in a table form and stored in Microsoft Excel spreadsheet. The data was then imported into statistical software R-studio/ Statgraphics Ver16 to compute descriptive statistics. From the descriptive statistics, measures of central tendency and data dispersion were computed for each treatment. The data was visualized by line graphs. Further statistical analysis was done as follows:

3.6.1 Analysis of Variance (ANOVA)

A One way Analysis of Variance (ANOVA) was conducted to see whether the influence of different treatments on these parameters (Initial weight and length, final length and final weight, FCR, SGR) was significant or not. The statistical model used was;

$$Y_{ij} = \mu + \tau_i + \epsilon_{ij},$$

Where:

Y_{ij} = the j-th observation

$j=1, 2, \dots, n_i$ on the i-th treatment

$i=1, 2, \dots, k$ levels

μ = the common effect for the whole experiment

τ_i = the i-th treatment effect

ϵ_{ij} = the random error present in the j-th observation on the i-th treatment

3.6.2 Analysis of Covariance (ANCOVA) for *O. niloticus* growth indicators

A one-way analysis of covariance (ANCOVA) was conducted to examine whether growth performance indicators (length or weight) were different among the treatment and the control groups while controlling for time in days(x). In general, since variations in days owing to temperature and other factors influence errors that cannot be randomized, they cannot be regulated in the experiment, they should be observed in tandem with growth performance indicators (length or weight (y)). Therefore the covariate in this one-way analysis of covariance (ANCOVA) is time in days (x). The treatment and control groups are the independent variables, and the growth performance indicators (length or weight) are the dependent variables. By controlling for time in days (x), the ANCOVA is able to examine whether the growth performance indicators are different among the treatment and the control groups. Assuming a linear relationship between x and y the appropriate statistical model will be:

$$Y_{ij} = \mu + t_i + Q(X_{ij} - \bar{X}_{.j}) + \varepsilon_{ij}$$

Where:

Y_{ij} is the growth performance as the response variable (weight or length) (the jth observation on the response taken under the ith treatment); $i=1, 2, \dots, a$ and $j= 1, 2, \dots, n$

$(X_{ij} - \bar{X}_{.j})$ is the covariate or the variable used in the control of error and adjustment of the means

μ is the overall mean of the growth performance indicator (length or weight gain)

t_i is the effect of the ith treatment (i.e., the treatment levels)

β is the linear regression coefficient indicating the dependency of Y_{ij} on X_{ij}

ε_{ij} - is the random error

The analysis of covariance model is a combination of linear models used in analysis of variance and regression, as seen in the equation. This means that we have treatment effects t_i as in one-way classification analysis of variance and a regression coefficient β as in regression analysis. The covariate is expressed as $(X_{ij} - \bar{X}_{.j})$ instead of X_{ij} so that the parameter μ is preserved as the overall mean.

3.6.3 Regression Analysis for growth performance indicators

A multiple linear regression analysis was used to determine the relationship between growth performance indicators (length and weight) and time in days based on the treatments. The slopes of regression were compared to identify statistically significant variations in slopes at various levels of *H. illucens* in the feeds, with the assumptions that the intercept remained constant and the size of *O.niloticus* fingerlings at the start of the experiment did not differ significantly.

The regression model is of the form:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \dots \beta_n X_n + \varepsilon$$

Where:

Y_i – is the growth performance indicator (length/weight)

X_1, X_2, X_3 – the independent variables (time in days based on the treatments)

β_0 - is the intercept (the point where the regression line cuts the y-axis),

$\beta_1, \beta_2, \beta_3, \beta_n$ - the regression coefficient slope (the change in length for every unit change in time (Days))

ε - is the random error

3.7 Economic analysis of *O.niloticus* fed diets supplemented with *H.illucens*

3.7.1 Cost effectiveness of diets supplemented with *H.illucens*

Using linear programming, the least expensive feed was determined based on the price of feed materials (kg), the dietary requirement of the fish diet and the total weight of the compounded feed. Diets were formulated using excel solver linear programming tool that incorporates linear programming in feed Formulation. The five diets were then compared to determine the cost effective diet that gives optimal growth rate with best FCR

Cost effectiveness of the diets

The cost effectiveness of the diets was calculated based on Incidence Cost (IC) and Profit Index as follows:

i)
$$IC = \frac{\text{Cost of feed used in fish grow out (KES)}}{\text{Weight of harvested fish (kg)}}$$

$$\text{ii) PI (Profitability Index) = } \frac{\text{Value of fish produced (KES)}}{\text{Cost of feed used (KES)}}$$

The cost of the formulated feed was calculated using the market price for the ingredients as well as the price per kg in the study area. A cost and return analysis was conducted using current pricing for all inputs and the value of marketable tilapia fingerlings. The input cost included the cost of fingerlings and the cost of feed ingredients such as rice bran, wheat bran, maize bran, cassava and labor.

3.7.2 Production cost analysis

The cost of various feed components and the volume of feed (kg) utilized in each treatment, were estimated (based on current market prices). The goal of the enterprise budget was to examine the relative profitability of the aquaculture business when *O. niloticus* consumed various *H. illucens* levels. Costs were classified as inputs, which were categorized as variable costs and fixed costs. The cost of fingerlings, feeds, hired labor and transport were variable costs. The aquaria cost, was included as an investment cost. Normally in production cost analysis in aquaculture, equipment and land are classified as fixed costs (Engle, 2010)

The profitability of the treatments assumed to be different enterprises were evaluated using the market price of *O. niloticus* in grams. The actual revenue values obtained after selling the fish were used in the analysis. The profit index (PI), as well as the economic conversion ratio, was determined. Retail prices in local market, expressed in Kenyan shillings, were used in the analysis. Gross profit, profit index and incidence of cost were the economic profit indices measured. In contrast, the viability index benefit/cost ratio was calculated using the recorded data during the experiment, which included stocking densities, kind of feed used, hired labor cost and other input expenses.

The gross profit margin of various treatments is used to determine profitability and the Gross Margin Analysis (GM) is given by the equation:

$$\text{GP} = \text{TR} - \text{TC}$$

Where; GP = Gross Profit, TR = Total Revenue (KES...), TC = Total Cost (KES...).

The general rule for Gross Profit is that if it is greater than zero, the business is generating more income.

Cost Benefit Ratio was calculated based on total revenue generated from the sale of produced fish. The cost-benefit ratio was represented by this revenue-to-cost ratio (CBR). A greater than one (>1) CBR value indicates that the benefits outweigh the costs, and vice versa.

3.7.2.1 Production Function Analysis

The Cobb Douglas production function was used to assess the relationship between production cost in treatments assumed as different enterprises and revenue. The model was designed to show how major variables affect the aquaculture production process. When there are three or more independent variables in the model, the Cobb-Douglas functional is usually utilized. Cobb-Douglas production functions are defined as follows. The cost is expressed in KES

$$\ln(Y_i) = \alpha + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \dots + \beta_6 \ln X_6 + \mu$$

Where:

Y_i = Profitability

X_1 = Feed cost (KES);

X_2 = Fingerlings' cost

X_3 = Electricity cost

X_4 = Hired Labor cost

μ = Random error term;

β_i = coefficients of the independent variables

α = Intercept

CHAPTER FOUR
RESULTS

4.1 Proximate analysis results of *H. illucens* and Fishmeal

The two protein sources of interest, fishmeal and *H. illucens* larva were analyzed for proximate (Table 4.1) according to AOAC (1995) procedures. The results of the proximate analysis show that the fishmeal had higher crude protein content than *H. illucens* larvae while the crude fibre and ether extract was lower in fishmeal compared to that of *H. illucens* larva. In contrast, the ash content in fishmeal samples was higher compared to that of *H. illucens* larva meal sample.

Table 4.1: Proximate Analysis results of *H. illucens* Larva and Fishmeal

Chemical Composition	<i>H. illucens</i> larva	Fishmeal
Dry Matter (%)	92.35	88.17
Ash (%)	4.62	15.20
Crude protein (%)	41.68	63.51
Crude Fibre (%)	8.64	0.27
Ether Extract (%)	41.03	14.49

After diet formulation, diets were also analyzed to determine the nutritional value and varying levels of crude protein. The diets were isonitrogenous approximately 30% crude protein (Table 4.2)

Table 4.2: Proximate analysis of Formulated Diets

Chemical Composition(%)	Diets				
	FM (0%)	BSF ₂ (25%)	BSF ₃ (50%)	BSF ₄ (75%)	BSF ₅ (100%)
Dry Matter (%)	89	89.5	89.8	89.8	89
Moisture (%)	11	10.5	10.2	10.2	11
Crude protein (%)	31.8	29.2	29.6	30.4	30.6
Crude Fibre (%)	4.5	4	6	6.5	5.5
Ether Extract (%)	6.4	7.6	6.8	8	8.4

4.2 Evaluation of physico-chemical parameters of water in aquaria

Water quality is important for growth performance and contributes to variation in growth. There were no significant differences in the physico-chemical parameters of water of any of the aquaria. The means and standard errors of water quality parameters are shown in Table 4.3. In all treatments, there were limited variations in the physico-chemical water quality parameters measures. The lowest mean pH was recorded at 6.96 in BSF₃ while the maximum being 7.23 in BSF₄. It was also observed that, the highest mean temperature recorded was 24.00°C, while the minimum mean temperature was 23.24°C. The lowest oxygen levels were recorded in BSF₃ at 4.31 Mg^{-L}, while the maximum levels were in BSF₄ at 4.91 Mg^{-L}. The highest quantities of ammonia were detected in BSF₄ at 0.12 Mg^{-L} with all the other treatments recording almost similar value.

Table 4.3: Mean values of physico-chemical parameters of water measured in aquaria (values are expressed as mean ± SEM)

Parameters	FM	BSF ₂	BSF ₃	BSF ₄	BSF ₅
%	0%	25%	50%	75%	100%
Temperature (°C)	23.46±0.2201	24.01±0.2835	23.24±0.1970	23.66±0.1914	23.44±0.2434
NH ₃ (Mg ^{-L})	0.02±0.0003	0.02±0.0004	0.02±0.0009	0.12±0.0526	0.02±0.0010
NH ₄ ⁺ (Mg ^{-L})	3.75±0.7219	3.36±0.1501	3.40±0.1562	3.58±0.0433	3.14±0.2166
Oxygen(Mg ^{-L})	4.83±0.2849	4.56±0.2425	4.31±0.2548	4.92±0.2960	4.91±0.2902
pH	7.14±0.1118	7.14±0.0909	6.99±0.1262	7.23±0.0751	6.95±0.1224

4.3 Effects of dietary supplementation with *H. illucens* larvae on *O. niloticus* growth performance

4.3.1 Growth performance of *O. niloticus* fed on *H. illucens* larva meal

One-way Analysis of Variance (ANOVA) was used to determine the differences in fish growth and survival based on the five treatments (Table 4.5). Post hoc pairwise comparison was conducted using the Fishers-LSD test. Overall, *O. niloticus* fed BSF₂ registered the

highest final length and weight. Unlike the initial weight, BSF₄ has a significantly different effect on *O. niloticus* final weight from BSF₂. However, BSF₂ final weight on *O. niloticus* was comparable to FM, BSF₃ and BSF₅. These results also applied to the weight gain and the daily weight gain. On the other hand, for final length, BSF₄ is significantly different from FM, BSF₂ and BSF₃ and was not significantly different from BSF₅. Furthermore, the same applies for the length gain and the daily length gain. The growth performance though is recorded highly in BSF₂, BSF₃ and FM respectively with BSF₄ performing lowest. In like manner to weight gain, the effect of BSF₄ specific growth rate varies significantly from BSF₂ and comparably to the other sets of treatments. Food conversion ratio on the contrary has the effects of BSF₄ significantly varying from FM, BSF₂ and BSF₃ except for BSF₅. The different treatments do not have a significantly different effect on survival of *O. niloticus*. The survival rates of *O. niloticus* are the same regardless of the feed applied.

Table 4.5: Growth performance of *O. niloticus* fed on diets supplemented with BSF (values are expressed as mean ± SEM)

Parameters	FM	BSF ₂	BSF ₃	BSF ₄	BSF ₅
	0%	25%	50%	75%	100%
Initial weight	14.96±0.07 ^a	14.82±0.06 ^a	15.00±0.06 ^a	14.72±0.60 ^a	14.90±0.12 ^a
Final weight	52.03±0.75 ^{ab}	53.83±0.76 ^a	51.41±0.00 ^{ab}	46.7 ±1.50 ^b	47.8±0.39 ^{ab}
Initial length	9.63±0.04 ^a	9.6±0.06 ^a	9.63±0.04 ^a	9.63±0.20 ^a	9.67±0.05 ^a
Final length	13.70±0.12 ^a	14.0±0.04 ^a	13.80±0.08 ^a	13.0±0.19 ^b	13.4±0.15 ^{ab}
Length gain	4.10±0.145 ^a	4.37± 0.02 ^a	4.13±0.10 ^a	3.33±0.20 ^b	3.77±0.11 ^{ab}
Weight gain	37.10±1.74 ^{ab}	39.00±0.29 ^a	36.40±0.97 ^{ab}	32.00±1.45 ^b	32.9±0.38 ^{ab}
Daily length gain	0.05±0.00 ^a	0.05±0. 00 ^a	0.05±0.00 ^a	0.04±0.00 ^b	0.05±0.00 ^{ab}
Daily weight gain	0.44±0.02 ^{ab}	0.46±0.00 ^a	0.433±0.01 ^{ab}	0.38±0.02 ^b	0.39±0.01 ^{ab}
SGR	1.48±0.04 ^{ab}	1.53±0.00 ^a	1.46±0.02 ^{ab}	1.37±0.03 ^b	1.39±0.00 ^b
FCR	0.73±0.01 ^b	0.71±0.01 ^b	0.74± 0.01 ^b	0.84 ±0.01 ^a	0.84±0.02 ^a
Survival	97.0±0.34 ^a	96.0±0.33 ^a	95.7±0.500 ^a	97.4±0.27 ^a	97.0± 0.33 ^a

Figures followed by the same alphabetical letter are not significantly different P>0.05

4.4 Evaluation of *O. niloticus* growth performance based on length on dietary supplementation with *H. illucens*

All fish groups showed a steady increase in length after feeding on the respective treatment diets (Figure 4.1) through the 84-day culture period, across all feeding regimes. During the first 30 days, all the curves displayed overlap; by the 40th day, the overlaps were between BSF₅ and FM and between BSF₂, BSF₄ and BSF₃. Nevertheless, by the 70th day in all the five treatments, all the curves were separated till the end of the experimental period except for BSF₃ which had the same final length as FM. On the final experiment day, the growth curves in the BSF₂ registered the highest length followed by FM, BSF₃ and BSF₅. BSF₄ resulted in the lowest length (Fig. 4.1).

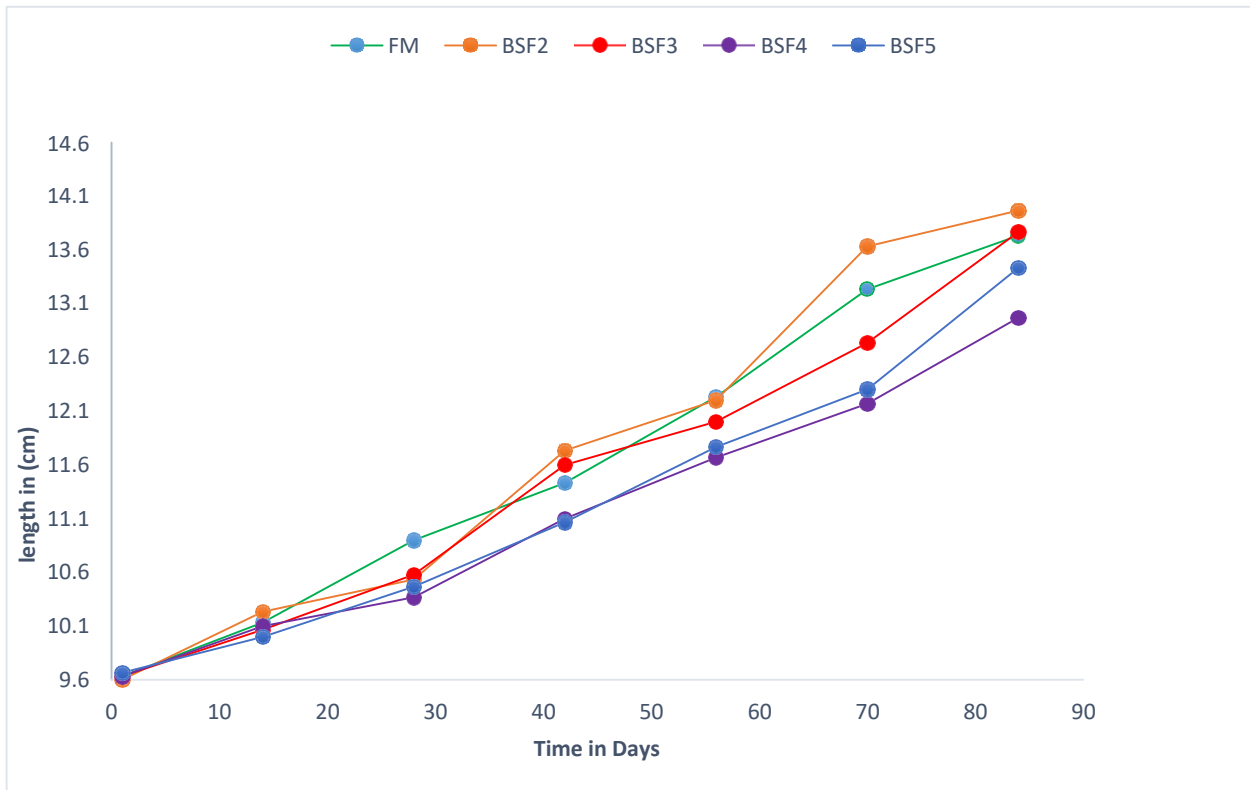


Figure 4.1: Growth performance of *O. niloticus* fed on different levels of dietary supplementation with *H. illucens*

4.4.1 Summary of Analysis of Covariance results based on *O. niloticus* length

The relationship between length, time, and treatment levels was examined for this study using a One-way Analysis of Covariance (ANCOVA). There was a significant difference in the treatment effect on length after accounting for time ($p < 0.05$) (Table 4.5).

Table 4.5: Summary of ANCOVA results on length with time as a covariate

Variation	DF	Sum of Squares	Mean Sum of Squares	F-value	Pr(>F)
Treatment	4	4,76	1.19	14.915	1.71e-09 ***
Time (days)	1	186.39	186.39	2335.508	< 2e-16 ***
Interaction	4	2.42	0.61	7.595	2.36e-05 ***
Residuals	95	456			

Fish fed on BSF₂, *H. illucens* at 25%, recorded the highest average length followed by FM (fish meal) with BSF₅ and BSF₄, *H. illucens* larva at 100% and 75% respectively, having the lowest records of average length. Least significant difference (LSD) shows that the effect of BSF₂ is significantly different from the effects of BSF₃, BSF₄ and BSF₅ but comparable to the effects of FM, (Table 4.6).

Table 4.6 Marginal means ± SE analysis on *O. niloticus* length

Treatment	Length
FM	11.61 ± 1.49 ^{ab}
BSF ₂	11.70 ± 1.61 ^a
BSF ₃	11.48 ± 1.42 ^b
BSF ₄	11.14 ± 1.16 ^c
BSF ₅	11.24 ± 1.29 ^c

Figures followed by the same alphabetical letter are not significantly different ($P > 0.05$)

4.4.2 Multiple Regression for *O. niloticus* Length and Days

The length and time in days were predicted using a multiple linear regression analysis based on the treatments (Table 4.6). The linear relationship between length gains over time in days was calculated in consideration for the treatment effects. A regression coefficient with an R^2

of 0.98 ($p < 0.05$) indicated that there was a significant relationship between the variables.

Table 4.6: Multiple linear regressions of length and days based on treatments

<i>Parameter</i>	<i>Estimate+SE</i>	<i>T</i>		<i>Co-efficients</i>	
		<i>Statistic</i>	<i>P-Value</i>	<i>Intercept</i>	<i>Slope</i>
CONSTANT	2.2536±0.0038	589.622	0.0000	2.2536	0.0045
Time (Days)	0.0045±0.0038	39.8885	0.0000	2.2536	0.0047
Time (Days)*Treat=BSF ₂	0.000±0.00013	1.55181	0.1239	2.2536	0.0043
Time (Days)*Treat=BSF ₃	-0.0002±0.0001	-1.64062	0.1040	2.2536	0.0036
Time (Days)*Treat=BSF ₄	-0.0009±0.0001	-6.83854	0.0000	2.2536	0.0038
Time (Days)*Treat=BSF ₅	-0.0007±0.0001	-5.02995	0.0000	2.2536	0.0045

The predicted Length, Time (Days) and Treatment was fitted in the model as;

$$\begin{aligned} \text{Log Length} = & 2.2536 + 0.0045 * \text{Time(Days)} * \text{Time(Days)} + 0.0002 * \text{Days} * \text{BSF}_2 \\ & - 0.0000 * \text{Time(Days)} * \text{BSF}_3 - 0.0000 * \text{Time(Days)} * (\text{BSF}_4 - 0.0006 \\ & * \text{Time(Days)} * \text{BSF}_5 \end{aligned}$$

When Treat = FM, the model reduces to; log of length = 9.415+ 0.051*Time (Days).

Treat = BSF₂, the model reduces to; log of length = 9.415 + 0.054*Time (Days).

The log of length of fish was predicted to increase by 0.051 daily. There was a significant difference for the slopes in the model with $p < 0.05$ level with different dietary treatment levels. A test for common slopes was conducted for the five treatments (Fig 4.2). The analysis showed that the five lines presented do possess significantly different slopes ($P < 0.05$) indicating distinct growth patterns (Figure 4. 2). *O. niloticus* increased more in length when fed FM, BSF₂, and BSF₃ than when fed BSF₄ and BSF₅. In comparison to FM, the linear regression slopes were less steep for BSF₃ BSF₄ and BSF₅. BSF₂ regression slope was highest compared to all the treatments. Days had a significant effect on weight $p=0.000$.

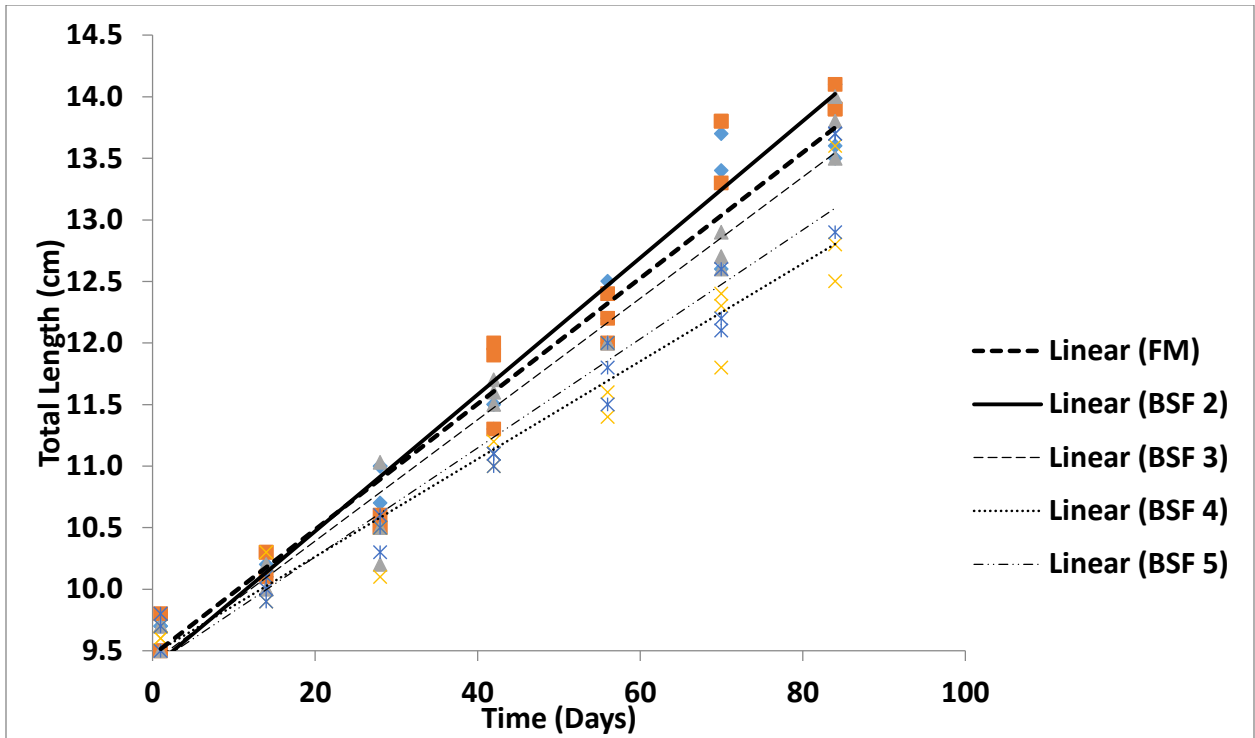
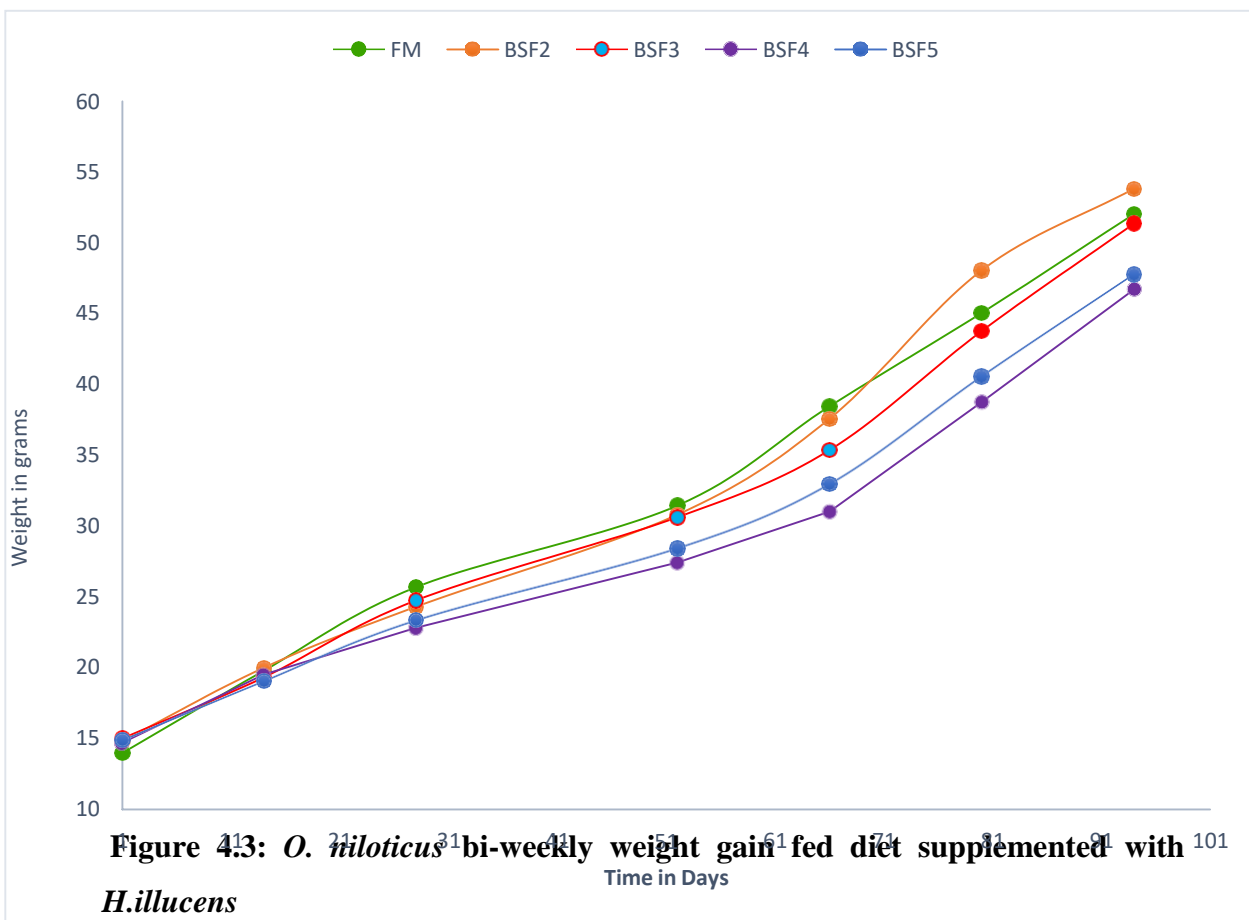


Figure 4.2 Graph of length regressed on time

4.5 Evaluation of *O. niloticus* growth performance based on weight gain on different dietary supplementation with *H. illucens*

O. niloticus growth performance in terms of weight followed a similar procedure as the length analysis. All fish groups showed a steady increase in weight after feeding on the respective test diets (Figure 4.3) through the 84-day culture period across all feeding regimes; FM, BSF₂, BSF₃, BSF₄, BSF₅. During the first 50 days, all the curves displayed some overlap; by the 60th day the overlaps were between BSF₅ and FM and BSF₂, BSF₄ and BSF₃. Nevertheless, by the 80th day in all the five treatments, all the curves were separated till the end of the experimental period. On the final day, the growth curves in the BSF₂ registered the highest weight followed by FM, BSF₃ and BSF₅ (100% *H. illucens* inclusion) BSF₄ resulted in the lowest weight.



4.5.1 Results of Analysis of Covariance (ANCOVA) based on treatment effect on *O. niloticus* weight

The treatments have a significant effect on growth performance in terms of weight ($p < 0.05$). Days equally has a significant effect on growth performance (Weight) ($p < 0.05$). The interaction effect between treatment and time is significant ($p < 0.05$), (Table 4. 7).

Table 4.7: Summary of ANCOVA results on weight with time (Days as a Covariate)

Variation	DF	Sum of Squares	of Mean Squares	Sum of F-value	Pr(>F)
Treatment	4	269	67	14.027	4.97e-09 ***
Time (days)	1	14546	14546	3030.509	< 2e-16 ***
Interaction	4	135	34	7.011	5.46e-05 ***
Residuals	95	456	5		

Fish fed on BSF₂, *H. illucens* at 25%, recorded the highest average weight followed by FM (fish meal) with BSF₄ and BSF₅, *H. illucens* larva at 75% and 100% respectively, having the lowest records of average weight. Least significant difference (LSD) shows that the effect of BSF₂ is significantly different from the effects of BSF₄ and BSF₅ but not significantly different from the effects of FM and BSF₃, (Table 4.8).

Table 4.8: Marginal means ±SE analysis on *O. niloticus*

Treatment	Length
FM	32.50 ± 12.51 ^a
BSF ₂	32.77 ± 13.81 ^a
BSF ₃	31.47 ± 10.78 ^a
BSF ₄	29.59 ± 11.17 ^b
BSF ₅	28.70 ± 12.97 ^b

Figures followed by the same alphabetical letter are not significantly different (P>0.05)

4.5.2 Regression of weight on days based on treatment levels of *H.illucens* on *O.niloticus*

To predict weight and time in days based on the treatments, multiple linear regression analysis (Table 4.8) was used. The relationship between the weight gains over time in days, considering the effects of the treatment, was assessed using the coefficient of correlation (r). There was a significant effect on the treatments and weight when controlling for time (Days) p<0.05 with an R² of 0.98. FM serves as the reference category and is included in the

intercept as a constant. As evidenced by $p = 0.000$ for both CONSTANT and Time (Days). Both time and treatments have a significant impact on the growth of *O. niloticus* (weight). BSF₄ and BSF₅ vary significantly from FM as shown by the $p = 0.000$. On the other hand, effects of BSF₂ and BSF₃ are comparable to the effect of FM ($p=0.5253$ and $p=0.1200$ respectively).

Table 4.8: Multiple regressions for weight and days based on treatments

<i>Parameter</i>	Estimate ±SE	<i>T-Statistic</i>	Co-efficient		
			<i>Intercept</i>	<i>Slope</i>	<i>P-Value</i>
CONSTANT	1.1935±0.0045	262.7490	1.1935	0.0066	0.0000
Time (Days)	0.0066±0.0001	49.4596	1.1935	0.0067	0.0000
Time (Days)*Treat=BSF ₂	0.0000±0.0001	0.63738	1.1935	0.0063	0.5253
Time (Days)*Treat=BSF ₃	-0.0002±0.0001	-1.56834	1.1935	0.0056	0.1200
Time (Days)*Treat=BSF ₄	-0.0000±0.0001	-6.37604	1.1935	0.0056	0.0000
Time (Days)*Treat=BSF ₅	-0.0007±0.0001	-4.68056	1.1935	0.0058	0.0000

The output shows the results of fitting a linear regression model to describe the relationship between weight, days and treatment. The equation of the fitted model is:

$$\text{Log weight} = 1.1935 + 0.0066 * \text{Time(Days)} + 0.0001 * \text{Time(Days)} * \text{BSF}_2 - 0.0002 * \text{Time(Days)} * \text{BSF}_3 - 0.0001 * \text{Time(Days)} * \text{BSF}_4 - 0.0007 * \text{Time(Days)} * \text{BSF}_5$$

When Treatment = FM, the model reduces to;

$$\text{Log Weight} = 1.1935 + 0.0067 * \text{Time (Days)}$$

When Treatment = BSF₂, the model reduces to;

$$\text{Weight} = \text{Log Weight} = 1.1935 + 0.0067 * \text{Time (Days)}$$

Log of weight of fish was predicted to increase by 0.0067 gram daily, (Table 4.8). The results showed that the five lines presented do possess significantly different slopes ($P < 0.05$), indicating distinct growth patterns, (Figure 4.4). The regression analysis showed that days significantly predicted weight.

O. niloticus gained more in weight when fed FM, BSF₂, and BSF₃ than when fed BSF₄ and BSF₅. In comparison to FM, the linear regression slopes were less steep for BSF₃, BSF₄ and BSF₅. BSF₂ regression slope was highest compared to all the treatments.

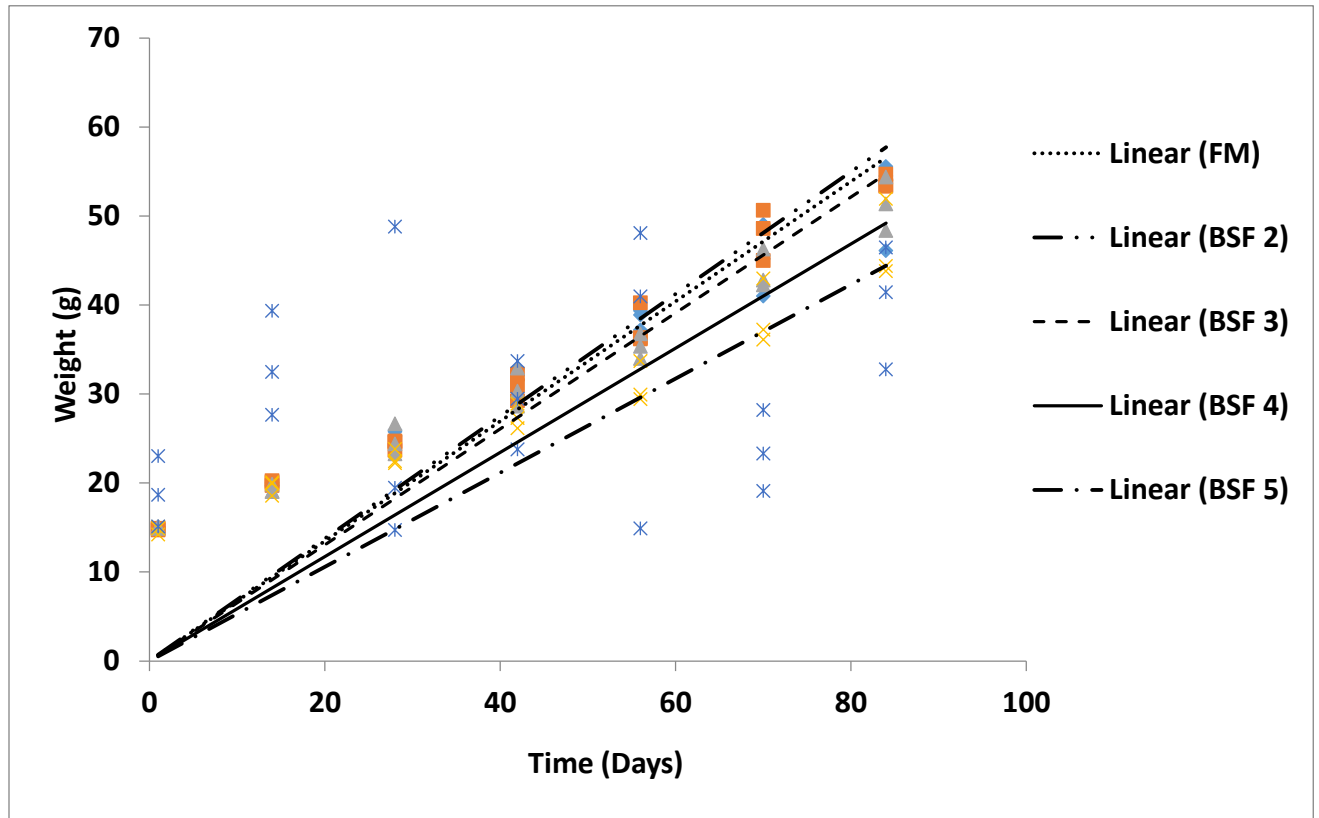


Figure 4.4: Graph of weight regression on time

4.6 Length-weight relationship of *O. niloticus*

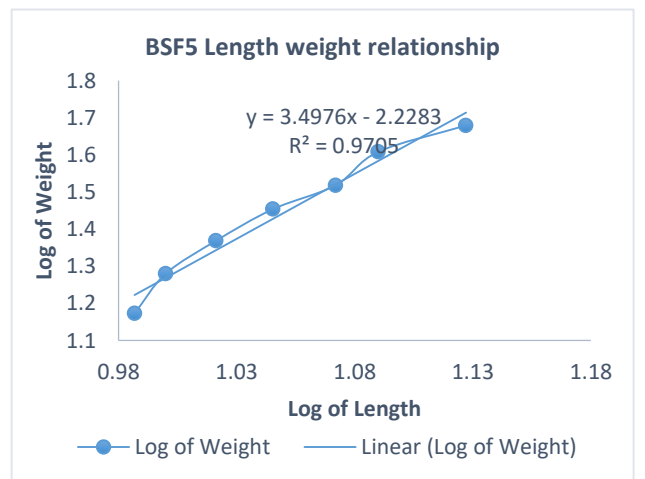
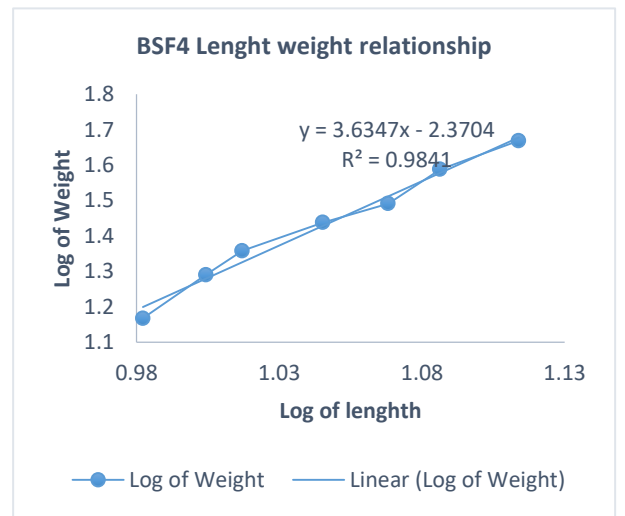
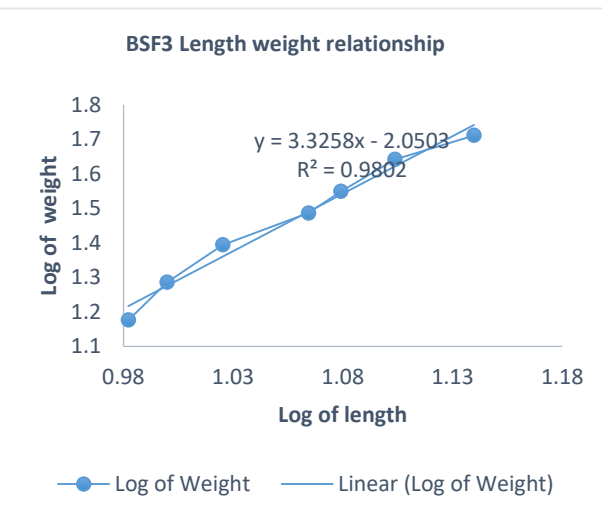
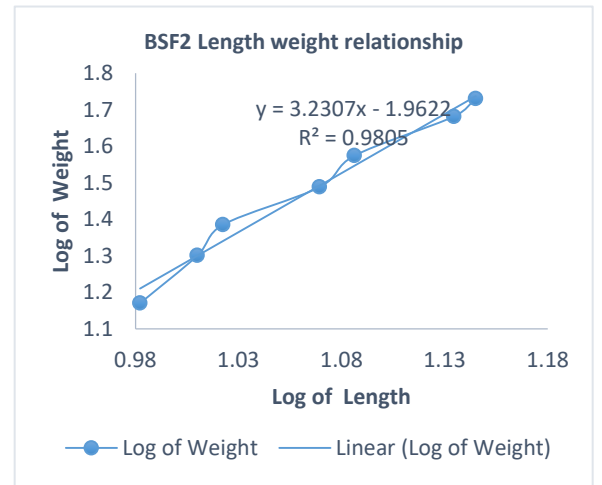
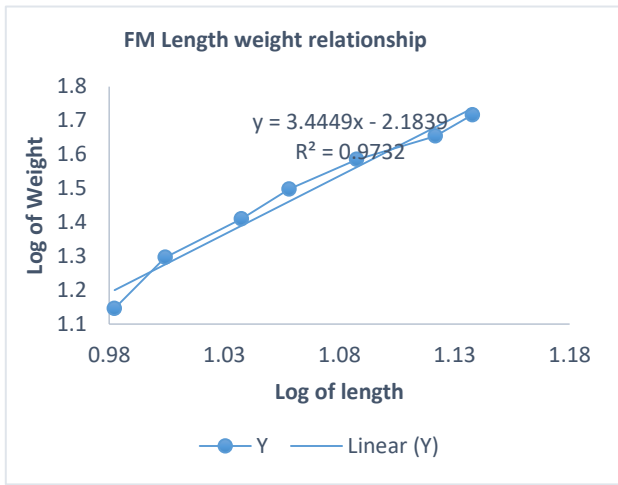
All treatments had high regression coefficient values (0.98-0.99) obtained from the length-weight relationship (Table 4.9). In this study results, mean value 'b' ranged from 3.23 to 3.63. BSF₄, BSF₅, and FM (3.63, 3.49, and 3.44, respectively) had a higher regression coefficient (b) than BSF₂ and BSF₃ (3.25, 3.23). The range of Fulton's condition factor K ranged from 0.9 to 1. BSF₂ had a condition factor of 1.00, while BSF₃ and FM had K values of 0.99 and 0.98, respectively. K values were 0.92 for BSF₅, 0.92 and 0.90 for BSF₄. BSF₄ had lower condition factors than FM, BSF₂, and BSF₃. The log-transformed data fit well in the linear

model (Fig 4.5) for all diets, with R^2 values above 0.9. Positive isometric growth was observed in all treatment diets.

Table 4.9 Length-weight relationship equation parameters and condition factor of *O.niloticus*

Diet	r	r²	a	b	k
FM	0.987	0.973	0.007	3.4448	0.994
BSF₂	0.990	0.981	0.010	3.230	1.002
BSF₃	0.990	0.980	0.009	3.326	0.980
BSF₄	0.992	0.984	0.005	3.635	0.907
BSF₅	0.985	0.971	0.006	3.498	0.926

Figure 4.5; Graph of the length-weight relationships of *O.niloticus* and prediction models by treatments



4.7 Effect of *H. Illucens* on *O. Niloticus* Production Cost

4.7.1 Cost Effectiveness of the Formulated Diets

In terms of feed cost, (Table 4.10) the diet supplemented with *H.illucens* at 100% BSF₅ was the most cost-effective (KES.52.14 kg⁻¹). The cost of a kilogram of feed decreased with increase in replacement of fishmeal with *H.illucens*. The control diet (FM) cost KES.71.23 with a crude protein of 31.8%. The 25% (BSF₂) inclusion level costing 66.45 kg⁻¹ with a crude protein content of 29%. The 50%(BSF₃) substitution costing KES.61.68 kg⁻¹ with a crude protein content of 29.6% while 75% (BSF₄) replacement costing sh.56.91 kg⁻¹ with a crude protein of 30.4%. The 100% BSF₅ had a crude protein of 30.6% and cost KES.52.14 kg⁻¹.

Table 4.10: Nutritional composition and cost of the formulated fish pellet diets

Treatment	Cost of formulated Diet (KES...)	Nutritional composition				
		CP %	EE %	CF%	ME/ Kg/DM	Ash
FM	71.23	31.8	6.4	4.5	17.95	6.72
BSF2	66.45	29.2	7.6	4.0	18.16	6.29
BSF3	61.68	29.6	6.8	6.0	18.37	5.85
BSF4	56.91	30.4	8.0	6.5	18.59	5.41
BSF5	52.14	30.6	8.4	5.5	18.9	4.97

DM- dry matter, CP- Crude protein, EE- ether extracts, CF - crude fibre, ME- Metabolizable energy per kg DM- dry matter, FM (Control) 0%inclusion of *H. illucens* larva, BSF₂,25%Inclusion of *H. illucens* larva, BSF₃,50% inclusion of *H. illucens* larva, BSF₄,75% inclusion of *H. illucens* larva, BSF₅,100%inclusion of *H. illucens* larva.

4.7.2 Profitability of *O.niloticus* fed Diets Supplemented with *H.illucens*

An enterprise budget was used to compare the profitability of *O.niloticus* fed diets supplemented with *H.illucens*. Each treatment is assumed to be a separate enterprise. FM had the highest cost of production, averaging (KES. **561.61**), while BSF₅ had the least cost at

(KES. 535.39). The cost of aquarium is a fixed cost and included in the enterprise budget as an investment. In terms of total yield, BSF₂ had the highest biomass at harvest of 2.69kg. BSF₅ had the lowest yield, with a biomass of 2.34 kg .The results of economic assessments of the five treatments as illustrated below in Table 4.11.BSF₅ had the lowest cost of producing a piece of *O. niloticus*, followed by BSF₄, BSF₃, BSF₂ and finally FM.

Table 4.11: Enterprise budgets for *O.niloticus* fed diets supplemented with *H.illucens*

Parameter	FM	BSF ₂	BSF ₃	BSF ₄	BSF ₅
	0%	25%	50%	75%	100%
Net Production (Kgs-84 days)	2.46	2.69	2.47	2.38	2.34
Price of feed/Kg	71.23	66.45	61.68	56.91	52.14
Total cost of feed	96.16	89.71	83.27	76.83	70.39
Total price of fingerlings	265	265	265	265	265
Total Transport costs	100	100	100	100	100
Hired Labor	100	100	100	100	100
Total variable costs	561.16	554.71	548.27	541.83	535.39
Variable costs/Unit	42.73	42.6	42.48	42.36	42.22
Fixed Costs	3000	3000	3000	3000	3000
Total costs	3561.16	3554.71	3548.27	3541.83	3535.39
Total Sales	896.56	960.69	916.78	833.42	852.69
Gross Profit	335.40	405.98	368.51	291.59	317.30
FCR	0.73	0.71	0.74	0.84	0.84
ECR	70.02	63.37	61.76	64.82	59.39
Profitability Index	9.32	10.7	11	10.84	12.11
Incidence cost	39.08	33.34	33.71	32.28	30.08
Contribution margin-cm sp-vc	257.27	257.4	257.52	257.64	257.78
Break Even Point fixed costs/cm	11.66	11.66	11.65	11.64	11.64
Break Even Sales	3498.27	3496.50	3494.87	3493.24	3491.34
BCR	1.60	1.73	1.67	1.54	1.59

Cost values are expressed in KES...

The ECR were compared for all the treatments. The analysis showed that the ECR in FM (control) was higher than in all the 5 treatments (70.02). BSF₂ and BSF₃ recorded ECR of

63.37 and 61.76 respectively while BSF₄ had an ECR of 64.82. BSF₅ had the lowest ECR of 59.39 illustrating more profitability when fed with inclusion level of *H. illucens* larva at 100%. These analyses indicated that the ECR of FM was higher than that of BSF₅. The Cost Benefit Ratio (CBR) was highest in the diet supplemented with *H.illucens* at 25%, however in all treatments the CBR>1 indicating that the benefits exceeded the costs.

4.7.3 Production Costs of *O.niloticus* Fed Diets Supplemented with *H.illucens*

The production function for this analysis (Table 4.12) had a bias in comparison of factors in all the treatments as the factors of production such as electricity cost, labor and transport costs, fingerlings were constant. The dependent variable for this analysis was the revenue

Table 4.12; Production Cost for *O.niloticus* Fed Diets Supplemented with *H. illucens*

Treatment	Total feed Cost	Price of fingerlings	Transport Costs	Electricity Cost	Labor	Total Revenue
FM	96.16	265	100	1000	100	896.56
BSF ₂	89.71	265	100	1000	100	960.69
BSF ₃	83.27	265	100	1000	100	916.78
BSF ₄	76.83	265	100	1000	100	833.42
BSF ₅	70.39	265	100	1000	100	852.69

Values are expressed in KES...

While the independent variables were total cost of feed, price of fingerlings, transport cost and electricity cost. The dependent variable for this analysis was the revenue while the independent variables were total cost of feed, price of fingerlings, transport cost and electricity cost. All the variable costs of production are constant for all the treatments assumed as individual enterprises, with the exception of total cost of feed and revenue obtained from the fish. The results of the regression analysis are as shown below in Table 4.13 below

Table 4.13: Summary of the coefficients from regression analysis

Unstandardized		Standardized					
Coefficients		Coefficients					
	B	Std.Error	Beta	T	P	– F value	
Model	(Constant)	5.375	0.869		6.186	0.009	2.663
	ln(TF)	0.321	0.197	0.686	1.632	0.201	

a. Dependent Variable: ln (Production)

There was no significant difference on total cost of feed and revenue $P > 0.05$. Because the values are natural logarithms, they have been converted to exponentials and the production function is written as; $y = 215.94 + 1.38TF^{0.686}$. Where, TF is the total cost of feed. The feeds were positively related to the productivity of the enterprise. The cost of production is predicted to increase by 1.38 shillings for each increase in total cost of feed. The coefficient of determination of the model (R^2) was 0.47, indicating that the valuation model explains 47 % of output. The adjusted value for R^2 was 0.29. The coefficient of the total cost feed was 0.321 the F value (2.663, $P > 0.05$) was not significant.

CHAPTER FIVE

DISCUSSION

5.1 Water quality and performance of *O.niloticus*

Water quality plays a critical role in growth and survival of fish. Low levels of oxygen and high ammonia levels in fish cause stress and leads to high mortalities. For optimal growth *O.niloticus* requires oxygen levels above 3Mg^{-1} and pH ranging between 7-9,(Ross, 2000),ammonia levels $< 0.05\text{Mg}^{-1}$ (Zeitoun *et al.*,2016) and temperatures between 25-30 °C (Rebouças *et al.*, 2016).

There was no significant difference in all the water quality parameters recorded ($p>0.05$).The water quality parameters taken were within the required range for fish growth in all treatments. The temperatures and pH physico-chemical parameters in the aquaria were within required limits for *O. niloticus* optimal growth (Rebouças *et al.*, 2016). The results of water quality analysis were closely related to those reported by (Tippayadara *et al.*, 2021).

The high ammonia quantities in the BSF₄ treatment could have contributed to the lower weight and length gain registered in diet at 75% inclusion of *H.illucens* compared to all the other treatments. Because there were no statistical differences on water quality between the treatment groups ($p > 0.05$), the differences in growth performance are due to the increasing levels of *H. illucens* in the *O.niloticus* diet. The current findings suggest that the diets used do not affect water quality as the survival of fish was not significantly different at the end of the experiment ($p > 0.05$) in all the treatments, indicating that water quality did not affect growth. Other water quality parameters were ideal for the growth of *O. niloticus*.

5.2 *O. niloticus* growth performance

The primary goal of this study was to evaluate the growth performance of *O. niloticus* when diets were supplemented with *H.illucens*. The growth performance study results show that growth varies consistently with increasing *H.illucens* supplementation levels. The results revealed that *O. niloticus* fed BSF₂ gained more weight and length than *O. niloticus* fed the control diet (FM). There were no significant differences in the weight and length of

O. niloticus fed BSF₂ and BSF₃ compared to the control (FM).

Furthermore, the low weight and length observed in *O. niloticus* fed diets at 75% and 100% could be attributed to the fish's low feed intake as a result of the diet's unfavorable flavor caused by the maillard reaction in the diets during drying and pelleting. Normally drying reduces crude fat levels in the diets. High crude fat levels also inhibit growth performance. Toasting, oven drying, or solar drying can reduce the crude fat content of *H. illucens* by 0.8-51%. The crude protein content of *H. illucens* increases during drying (Nyangena *et al.*, 2020). When insect meal is dried, however, a phenomenon known as the maillard reaction occurs; this either improves or degrades the taste of the feed, influencing palatability and feed intake (Tamanna and Mahmood, 2015). The diet's palatability may have been impacted by the use of more sun dried *H. illucens* in the diets supplemented at 75% and 100% in this study because more amounts of *H. illucens* were used, which could have changed the flavor of the diet and decreased feed intake. Moreover, the presence of fishmeal in the diet is low at 75%, whereas it is totally removed in the feed at 100%. *O. niloticus* is naturally drawn to fishmeal in their meals because it is more digestible, appealing, and tasty to them (Ryder and Balaban, 2011). According to Kroeckel *et al.* (2012), reduced palatability is typically found in diets when fishmeal is primarily substituted by alternative protein sources, particularly if they contain anti-nutritional components (ANFs). To preserve the flavor of *H. illucens*, the drying period should not be prolonged.

The low weight and length in *O. niloticus* fed diets supplemented at 75% and 100% could have also been attributed to the low digestibility as seen in the low FCR realized by BSF₄ and BSF₅ compared to the other diets. All treatments had a significant difference in FCR, with BSF₄ and BSF₅ being significantly different from FM, BSF₂ and BSF₃. On the other hand, *O. niloticus* fed BSF₂ had the highest SGR (1.53±0.00) and the best FCR (0.71±0.01). The results of the FCR and SGR concur with those reported by (Kroeckel *et al.*, 2012).

According to the results, supplementation of the diets at 75% and at 100% (BSF₄ and BSF₅) could have caused the low feed intake in fish and indigestibility resulting in decreased FCR,

low weight, and smaller *O.niloticus* in weight and length. The amount of chitin in *H.illucens* containing diets appears to have a deleterious influence on feed intake, growth, and digestibility (Cummins *et al.*, 2017; Xiao *et al.*, 2018).

Low growth performance may have been caused by the high chitin levels in fish fed diets supplemented with *H. illucens* at 75 and 100%. According to St. Hilaire *et al.* (2007), diets containing more *H. illucens* meal have more chitin and are therefore less digestible. Additionally, the increased levels of chitin in the diets may have caused growth to be slower at the 75% and 100% *H. illucens* diets. The inability of most fish to digest high levels of chitin has been linked to poor growth performance (Nogales-Merida *et al.*, 2018), which inhibits lipid digestibility and limits nutrient absorption from the intestinal tract (Nairuti *et al.*, 2021).

However, the FCR discovered in this work at 25% and 50% supplementation levels suggests that *O. niloticus* may be extremely adept at digesting chitin or tolerant of certain concentrations. Studies by El-Sayed (1998) and Cavalheiro *et al.*, (2006) suggest that shrimp meal, which is heavy in chitin, can be used in place of fish meal without harming (*Oreochromis spp*), *Oreochromis niloticus*, or *Oreochromis urolepis hornorum*.

Increasing the quantity of *H. illucens* larval meal and decreasing the proportion of fishmeal impact the protein quality in the diet. The protein quality of a fish diet is determined by the required amino acids in the correct ratios (Diógenes *et al.*, 2016). The amino acid quality of the *H.illucens* supplemented at 75% and 100% may have been significantly poorer, especially for the essential amino acid requirement. Increased levels of *H. illucens* in fish feed have been reported to restrict fish development due to taurine shortage in *H. illucens*-based diets (Magalhes *et al.*, 2017). Suggesting that adding restricted essential amino acids and modifying the non-essential and essential amino acid ratio of replacement meals can result in considerable increases in fish performance at higher levels of *H. illucens* larva inclusion (Cummins *et al.*, 2017). Fish performance may be greatly enhanced by supplementing the *H.illucens* diet with restricted essential amino acids, such as taurine, and

altering the ratio of non-essential and essential amino acids in replacement meals.

The fortification of nutrients may have led to an increase in weight in *O. niloticus* fed BSF₂ and BSF₃. Ogunji *et al.* (2011) found that when fishmeal is combined with maggot meal in the diet of carps up to a specific level, there appears to be a form of nutritional fortification. Ogunji *et al.* (2011) discovered that maggot meals have more balanced amino acid profiles than numerous other potential protein sources.

According to Kamarudin *et al.* (2021), fish fed diets supplemented with *H.illucens* up to 100% exhibited inferior development performance. This result suggests that supplementing fish diets with *H.illucens* may not always result in increased growth performance and may even be deleterious in some situations. In the current investigation, there were no signs of nutritional deficiency or death. Slower growth performance of *O. niloticus* when given *H. illucens* was supplemented at 75% and 100% shows a positive association between reduction in growth and increased amounts of *H. illucens* larva meal in the diet.

The body weight gains, length gains and SGR of *O. niloticus* slightly decreased when *H. illucens* supplemented Fishmeal beyond 50%. These findings suggest that a higher dietary inclusion of *H. illucens* inhibited the growth performance of *O. niloticus*. Therefore, supplementation of *H.illucens* by up to 50% is more profitable for farmers and contributes towards more yields. Enhanced performance could be attributed to palatability and improved essential amino acid profiles in diets below 50% (Kamarudin *et al.*, 2021) leading to increased feed intake by the fish.

Barroso *et al.* (2014) discovered that *H. illucens* larva meal had the most similar amino acid profile to fishmeal across a variety of insect species, which could explain the particularly positive results in growth performance of *O.niloticus* supplemented with *H.illucens* across all diets in the current experiment. The research supports the current study's findings by arguing that the high quality protein found in *H. illucens* larva meal makes it a viable substitute for fishmeal as a feed component in aquaculture.

The presence of chitin in the *H. illucens* larva meal could also explain aspects of performance improvement at 25% and 50% *H. illucens* inclusion levels. Low levels of chitin in *H.illucens*-based diets improve fish growth and mitigate the negative effects of fishmeal replacement (Fontes *et al.*,2019). The current study's findings concur with those reported by Muin *et al.* (2017) that showed significant variations in growth when *H. illucens* completely substituted FM beyond 50%.The current study results differ from those of Tippayadara *et al.* (2021) and Nairuti *et al.* (2021) who demonstrated that up to 100% replacement of fishmeal with *H. illucens* larva meal is possible with no negative impact on growth performance. Although there were no adverse effects on *O. niloticus* fed *H. illucens* meal up to 100%, optimal growth and revenue is obtained by substitution level of up to 50%. Using *H.illucens* larvae meal by up to 50% is more economical as farmers have optimal growth and produce at reasonably lower cost compared to fishmeal.

All of the dietary treatments in the current study had survival rates exceeding 95%. Fish fed on BSF₄ had the highest survival (97.40%), while fish fed on BSF₂ had the lowest (95.7%), indicating that *H. illucens* meal had no detrimental consequences on the fish's ability to survive. Since most mortalities were noticed a day following length and weight measurements, the mortality that was found may have resulted from stress during sampling.

5.2.1 *O. niloticus* length -weight relationship

BSF₄ diets had a higher value of positive isometric growth ($b=3.63$) than the control, FM diet ($b=3.44$), and the other three diets, BSF₂ ($b=3.23$), BSF₃ ($b=3.33$), and BSF₅ ($b=3.49$), indicating that fish become more rotund as their length increases. *O.niloticus* fed FM and diets supplemented with *H.illucens* BSF₂, BSF₃, BSF₄, and BSF₅ all had isometric growth, indicating that as the *O. niloticus* increases in length, it becomes heavier for its weight.

The high coefficient of determination 'R' values in each treatment indicated that these *O. niloticus* equations were relatively accurate. Fulton's condition factor K had a range of 0.9 to 1. The condition factor for BSF₂ was 1.00, while the condition factors for BSF₃ and FM were 0.99 and 0.98, respectively. BSF₅ 0.92 and BSF₄ 0.90 had lower condition factors than FM,

BSF₂, and BSF₃.

The length weight relationship's findings were consistent with those of Anani and Nunno's (2016) study, which demonstrated isometric growth ($b \geq 3$) growth in Nile tilapia fed with farm-made tilapia diet. The findings of this study contrast with those of Mugendi *et al.* (2022), who discovered that *O. niloticus* fed commercial diets supplemented with duckweed (*Lemna minor*) initially exhibited allometric growth before switching to isometric growth at the sixth week.

For all treatments, the condition factor (K) was approximately 1 (Table 4.9). The diet supplemented with *H. illucens* at 25% had the highest condition factor of all treatments. These findings suggest that *O. niloticus* were in good health throughout the experiment. Despite having higher isometric growth than *O. niloticus* fed FM, BSF₂, BSF₃, and BSF₅, *O. niloticus* supplemented with *H. illucens* at 75% had the lowest condition factor (0.9) in comparison to the other experimental fish. As evidenced by the fish's low final weight, the low condition factor in *O. niloticus* fed diets supplemented with *H. illucens* at 75% indicates that it had poor feed intake compared to the others. According to Bagenal (1978), the fish condition factor also reveals a species' level of feeding activity to demonstrate whether it effectively utilizes its feeding resource. Based on the condition factor of BSF₂ (K=1) and ($b=3.2$), *O. niloticus* thrives more on diets supplemented with *H. illucens* at 25% compared to other levels of supplementation. Fish with a higher condition factor (above 0.9) are typically healthy and thriving. In contrast, a lower condition factor (below 0.9) might suggest that the fish is underweight or malnourished (Samson, 2022).

While all of the fish in the current study were in good health and condition, the condition factor registered was lower than that of Luo *et al.* (2011), who reported a higher condition factor above 3 in all diets when *O. niloticus* was fed diets supplemented with betaine in aquaria. The results could be attributed to higher water quality parameters observed compared to the current study. Anani and Nunno (2016) also registered condition factors above 1 when *O. niloticus* was fed with commercial and farm made diets. The condition

factor reported is closely related to that Shahabuddin *et al.* (2015) who reported condition factors of about 1 when juvenile *O.niloticus* were fed diets with *Pyropia spheroplasts*.

Since all of the fish in the experiment were male, their condition factors were nearly identical and the $K \geq 0.9$ range. Male fish have larger bodies and more flesh than females (Bhatta *et al.*, 2012). The results of the length weight relationship demonstrated that the *O.niloticus* were in good health when fed diets supplemented with *H. illucens* larva.

The current study finding supports that the *O. niloticus* can be reared with diets supplemented with *H. illucens* larva meal without harming their physiology. The results of this study support Cren (1951) finding that a fish's shape or body outline typically changes throughout its life. Studies on the length-weight relationship and condition factor of *O.niloticus* fed diets supplemented with *H.illucens* are scarce.

5.3 Economic analysis of *O. niloticus* fed on varying levels of *H. illucens*

5.3.1 Evaluation on the cost effective diets

The economic performance in terms of incidence costs and profit index varied in all the treatments. All the diets have a high profitability index and lower incidence cost compared to the control diet. However, in terms of cost-effectiveness and growth performance it is only BSF₂ which is more superior to the control diet.

The highest profit index was found in the BSF₅ and BSF₄ diets, owing to the relatively low market prices of *H. illucens* larva and the total lack of fishmeal in the BSF₅. However, BSF₂ had the highest yields compared to the rest of the treatments. BSF₅ high profitability index illustrates that feed cost had an impact on the overall profitability in aquaculture. The results were similar to those of Limbu *et al.*, (2022) who reported increased profitability index with increased supplementation of *H.illucens* in *O.niloticus* diet.

FM based diet was the most expensive in producing a kg of fish feed. The high cost of the FM based diet was contributed by the high price of fishmeal (KES.200/kg). On the other hand,

diet supplemented with *H.illucens* at 100%, BSF₅, had a lower cost contribution in producing a kg of *O. niloticus* feed. The low price is due to the low market value of the black soldier fly larva meal (KES.80/kg).

The diet supplemented with *H.illucens* at 100% BSF₅ was the most cost-effective (KES.52.14 kg⁻¹). The BSF₅ diet resulted in a KES.19.09 kg⁻¹ economic savings, representing a 26.8% reduction in production costs compared to the control diet. These findings are consistent with those of Udo *et al.* (2019), who discovered a significant reduction in the cost of catfish fingerling feed when linear programming was used. Furthermore, Olorunfemi (2006) reduced feed costs by about 20.82% when formulating a broiler finisher diet with linear programming and a non-traditional protein source, duckweed. The complete replacement of fishmeal protein source with black soldier fly larvae meal significantly reduced feed formulation costs.

The findings demonstrate that the low cost of black soldier fly larvae meal reduces costs in the production of fish feed. Increasing fish farm profits requires a minimization in the cost of feed and making considerable effort to finding alternatives of fishmeal from both plant and animal protein sources. Black soldier fly larvae meal's production cost is relatively low because it can be raised on wastes

5.3.2 Profitability of supplementing *H. illucens* in *O. niloticus* diets

In the production cost analysis, more revenues of about KES(960.69)were obtained in BSF₂, 25% supplementation of *H.illucens* .It also incurred the highest cost of production of about KES(561.16) compared to all treatments. At 100% supplementation of *H. illucens* BSF₅, the cost of production was lowest at about KES (535.39) with least returns realized. BSF₂ outperformed the control diet in terms of revenues realized in the enterprise. The feed cost had the lowest cost contribution in all treatments. Due to low economies of scale, only a small quantity of fish consumed the formulated diets even though other cost such as electricity cost and labor varied due to the extended period of the study. The price of aquaria was factored in as an investment.

All the enterprises were profitable with diets supplemented with *H.illucens* larva meal at 25% having the most profits. The current study results were different from that of Ouma (2019) who reported negative marginal profits or losses in all treatments in the first trial of *Clarias gariepinus* fed diets of plant protein origin with different crude protein levels, varying levels of *H. illucens* larva in the diets caused differences in economic performance for the rations. Minimum quantities of *H. illucens* larva in the diets increased the overall cost of production in treatments with less replacement such as BSF₂ BSF₃ and FM. Increased levels of *H. illucens* in the diets decreased the production costs as seen in BSF₄ and BSF₅ diets (Table 4.11). The cost of feeding was reduced when fishmeal was replaced with *H. illucens* larva meal. Wachira *et al.* (2021) reported similar results where cost of production reduced with increased supplementation levels of *H.illucens* in *O.niloticus* diets.

These findings demonstrate that partial replacement of fishmeal with alternative insects based proteins is more profitable and that cost of feed contributes towards profitability in aquaculture. As much as 100% replacement of *H. illucens* larva meal is more cost effective, BSF₅ in *O. niloticus* yields minimal returns. Therefore, BSF₂, replacement at 25% and at BSF₃ 50% are therefore give optimal returns treatment since they realized higher *O. niloticus* growth performance and contributes optimal profits. The findings of the study on the growth performance leads to the conclusion that BSF₂ (25% *H. illucens* larva meal) and BSF₃ (50% *H. illucens* larva meal) give optimal growth performance and profits and could therefore replace the control diet in aquaculture. The study revealed that the use of *H. illucens* larva meal in the diet of *O. niloticus* reduces cost of production while enhancing growth performance.

Revenue from fish was highest in BSF₂ due to the increased yields and better growth. Furthermore, the current findings on *O. niloticus* growth performance revealed that *H. illucens* could supplement fishmeal by 50% in *O. niloticus* diets. These findings differ from those of Tippayadara *et al.* (2021), who discovered that replacing *H. illucens* with fishmeal by up to 100% did not result in a decrease in *O.niloticus* growth performance. The high performance at 100% could be attributed to the low lipid content of the formulated diets

(4%), which was achieved by oven-drying the *H.illucens* before formulating the feed to reduce fat content. *O.niloticus* diets with high lipid content inhibit growth. The crude fat content in the current study ranged from (6.4-8.4%).

There was a bias in the production cost analysis in all the treatments. Production costs such as electricity cost, labor, transport costs, fingerlings, were constant. The R^2 was 0.47 indicating that the inputs considered in the function play 47 % of the role in predicting total revenue and that 47% of the variations in fish yield, is attributable to the cost of feed. Based on the estimates of the modified translog production function, equation the main factors affecting production was feed cost explaining 47 % of the variation in productivity. Other factors, such as hired labor and fingerling cost, do not significantly affect the output level because all these factors were constant in all the treatments.

The coefficient of the total cost feed was 0.321 ($P>0.05$) was not significant. The results show that total feed could not predict the revenue from fish. Other variables were omitted due to collinearity. The results obtained are due to the fact that the factors of production were constant in all treatments except for the feeds. The feeds were positively related to the productivity of the enterprise. The results of the analysis are presented in (Table 4.14) above.

Estimation of returns to scale is imperative as it points out the scale at which firms are most efficient. The return to scale was found to be 0.686 for fish production. The results show that production function demonstrated a decreasing return to scale illustrating that 1 % increment in all the factors of the production leads to a 0.686 % increment in income. The enterprise was in the initial production stages hence there are minimal profits. The results are similar to those reported by (Rahman and Miah 2001) that showed diminishing returns to scale. The diminishing returns to scale can be attributed to the incomplete cycle in fish growth in the experimental trial and the small scale production. The results suggest that farmers should grow fish to the marketable size as well as at maximize economies of scale to increase profitability in aquaculture. These results are different from those reported (Asamoah *et al.*, 2012) which showed increasing returns to scale in fish output. Minimal studies have considered the Cobb Douglas production function for experimental fish farms.

CHAPTER SIX

6.1 CONCLUSION

From the results and limitations of this study the following conclusions were made:

- *H.illucens* larvae's potential as a sustainable feed component for Nile tilapia production is highlighted by the diet's lowered cost. Adding black soldier fly larvae to Nile tilapia diets entirely results in significant cost reductions, equivalent to a roughly 26.8% decrease in feed costs.
- Based on our current data, we may infer that *H. illucens* larval fish meal can be added in the diet of *O. niloticus* without generating substantial decreases in body weight increase, FCR, or up to 50% of the time. Despite the fact that *O. niloticus* given the highest amount of BSF-meal (BSF₅ 75) had the worst growth performance, there were no indicators of nutritional shortages or greater mortalities.
- In addition larger yields and greater returns were obtained in diets supplemented with *H. illucens* between 25 and 50%. According to these findings, the aquaculture business may see greater profits if farmers supplemented the *O.niloticus* diets with *H. illucens* between 25 and 50%. As a result of the findings, replacing *H.illucens* meal for fish meal up to 50% of the time may be a viable strategy to cut expenses and boost the sustainability of *O. niloticus* production.

6.2 RECOMENDATIONS

Recommendations based on the study

This study recommends:

- Supplementation of fishmeal with *H.illucens* larva meal up to 50% for maximum growth and optimal profits. The high levels of lipid in the diet supplemented up to 100% can be reduced by drying the *H.illucens* before its use as feed because high lipid levels in diets of *O.niloticus* inhibits growth.
- Farmers may utilize excel spreadsheets with linear programming to create cost-effective diets with the support of fisheries extension specialists. As a result, linear programming with an excel solver will go a long way toward developing low-cost feeds for the aquaculture business and assuring the sector's viability. Furthermore, the economic impact of using *H.illucens* as a feed component might be considerable, since it could assist farmers better manage the expenses associated with Nile tilapia aquaculture operations.
- From an economic view, the study recommends that fish farmers should produce fish in large scale and up to marketable size for sale to optimize productivity. Therefore, if farmers increase their production levels more profits can be realized. The low profit margins in all the treatments were realized because of the low economies of scale and because the fish did not reach the market size. Therefore, if farmers increase their productivity levels more profits can be realized.
- The high levels of lipid in the diet supplemented up to 100% can be reduced by drying the *H.illucens* before its use in feed. The crude fat content of *H. illucens* can be reduced by toasting, oven drying or sun-drying.

Recommendations for Further Study

- More research may be done to find out how well *O.niloticus* grows when fed diets made of toasted, oven-dried, or sun-dried *H. illucens*. These three approaches of preparing the feed for *O. niloticus* may significantly affect their pace of growth and may reveal useful information about the best ways to promote their health and growth.
- Additionally, additional investigation might be conducted to ascertain the variations in the protein, lipid, and fatty acid profiles of the diets composed with toasted, oven-dried, or sun-dried *H.illucens*. A cost analysis of the diets may offer details about the revenue received and its profitability. The diets of *O. niloticus* may be optimized by aquaculture farmers based on these findings in order to increase productivity.

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