

**SOCIO-ECONOMIC EFFICIENCY OF BLACK SOLDIER FLY (*Hermetia illucens* L.)
LARVAE MEAL FOR AQUACULTURE PRODUCTION**

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the Award of a Degree of Doctor of Philosophy in Food Security and Sustainable
Agriculture of Jaramogi Oginga Odinga University of Science and Technology**

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@ AUGUST 2023

DECLARATION AND APPROVAL

Declaration

I declare that this thesis is my original work, and it has not been submitted in whole or in part for the award of any degree at this or any other educational institution.



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DEDICATION

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ABSTRACT

Fish feed is a major component in aquaculture production, accounting for 40-80% of total production costs. Protein is still the most expensive ingredient in fish feed. Fishmeal (FM) has traditionally been the predominant fish diet for aquaculture production in Kenya where Nile tilapia has been the dominant fish species. However, with declining catch fisheries, FM has become increasingly rare and expensive as a result of its demand from the human food and animal feeds industries. Due to the increased price of fish feed, farmed fish have low profit margins. For the industry's growth, it is therefore necessary to produce palatable and long-lasting alternative feeds that are inexpensive and nutritionally balanced. Despite being viable FM substitutes, insect-based protein sources like Black Soldier Fly Larvae (BSFL) have not been extensively studied for their economic use in aquaculture. In this study, the socioeconomic efficiency of using BSFL meal to replace fish meal in aquaculture production in Kenya was evaluated. The study's specific objectives were: 1) to determine the technical efficiency of BSFL in aquaculture, 2) to assess the economic efficiency of BSFL in aquaculture production, and 3) to evaluate the acceptability of BSFL in aquaculture production. To address technical and economic efficiency aspects, BSFL meal was used to substitute fish meal in the meals at 0% (control diet), 25% (Diet T2), 50% (Diet T3), and 75% BSFL inclusion levels (Diet T4). Awareness, perceptions, attitudes, and intentions to use BSFL meals in aquaculture were investigated to address the social efficiency element. Primary data were collected from 211 fish farmers in Kenya's Siaya, Kisumu, and Homabay counties using a cross-sectional survey design. To assess farmers' awareness, a binary logistic model was applied. With the use of SmartPLS 3.0, a structural equation model was used to investigate hypothesized paths of the Technology Acceptance Model (TAM) in the adoption of BSFL meal. Purposive sampling was utilized to select 40 experts, 24 of whom responded to the Delphi study. Kendall's coefficient of concordance was used to evaluate expert consensus. According to the findings, there were no significant differences in growth performance indicators, however, diet T3 was the best in terms of final mean weight, weight gain, daily weight gain, survival rate, Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), and Feed Efficiency (FE). T3 was the most effective FM substitute for Nile tilapia fry for a lucrative and sustainable aquaculture business, with an 8.94% cost savings when compared to the control diet. An analysis of the cost effectiveness of the various diets revealed that diet T3 provided more economic advantages per kilogram of fish produced than the other diets. Over 53.6% of the fish farmers were aware of insect-based feeds but only 1.9% of the fish farmers had used BSFL in aquaculture. Awareness of insect-based feeds (IBFs) varied significantly across counties ($\chi^2 = 9.008$, $P = 0.011$). The results of the binary logistic regression revealed that farming experience ($p < 0.01$), distance to feed sources ($p < 0.05$) and knowledge about components of existing feed ($p < 0.01$) positively significantly affected the farmers' awareness of BSFL based aquafeeds, while farmers' income ($p < 0.01$) negatively significantly affected the farmers' awareness of BSFL. The results further indicated that fish farmers' intention to use BSFL can be predicted by Attitude ($\beta = 0.411$, $p = 0.000$), Perceived Usefulness ($\beta = 0.319$, $p = 0.000$) and Perceived Ease of Use ($\beta = 0.178$, $p = 0.004$) with attitude having the greatest influence. According to Delphi study results, all stakeholders agreed that BSFL should be used as an alternative protein element in aquaculture. The assessment of the perceived benefits BSFL in aquafeed was statistically higher than the perceived risks, indicating a higher level of acceptability. Overall, this study suggests that a 50% inclusion level of BSFL, which is relatively cheap than conventional fish feeds. It is thus important to raise awareness and promote the use of BSFL in fish production by relevant government departments among fish farmers through multiple publicity channels and media.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASARECA	Association for Strengthening Agriculture Research in East and Central Africa
ASTGS	Agricultural Sector Transformation and Growth Strategy
ATT	Attitude
AVE	Average Variance Extracted
BSFL	Black Soldier Fly Larvae
CAGR	Compound Annual Growth Rate
CB-SEM	Covariance-based Structural Equation Model
CO₂	Carbon (IV) Oxide
CP	Crude Protein
DM	Dry matter
DO	Dissolved Oxygen
ECR	Economic Conversion Ratio
EFSA	European Food Safety Authority
EPI	Economic Profit Index
FA	Fatty Acids
FAO	Food and Agriculture Organization
FCR	Feed Conversion Ratio
FE	Feed Efficiency
FM	Fishmeal
IBF	Insect-based feed
IC	Incidence Cost
IM	Insect meal
INSFEED	Insect feed for poultry and fish production in sub-Saharan Africa
INT	Intention to use
JOOUST	Jaramogi Oginga Odinga University of Science and Technology
KEBS	Kenya Bureau of Standards
Kg	Kilogram
KMFRI	Kenya Marine and Fisheries Research Institute

KNBS	Kenya National Bureau of Statistics
KSh	Kenya Shillings
MJ	Megajoule
MT	Metric Tonnes
NACOSTI	National Commission for Science, Technology and Innovation
PCA	Principal Component Analysis
PEOU	Perceived Ease of Use
PLS-SEM	Partial Least Squares Structural Equation Modeling
PU	Perceived Usefulness
SDGs	Sustainable Development Goals
SEM	Structural Equation Model
SGR	Specific Growth Rate
TAM	Technology Acceptance Model
TVC	Total Variable Cost
USD	United States Dollars
VIF	Variance inflation factor
WTA	Willingness to Accept
WTB	Willingness to Buy
WTP	Willingness to Pay
WTT	Willingness to Try

CHAPTER ONE: INTRODUCTION

1.1 Background information

Aquaculture is one of the fastest-growing food sectors in the world, accounting for more than half of all fish and seafood output (FAO, 2020). It is critical in third-world countries such as Kenya for the supply of food, livelihood, and revenue (Beveridge *et al.*, 2013; Bene *et al.*, 2016; Wanja *et al.*, 2020). The current global human per capita fish consumption is estimated at 20.5 kg annually (FAO, 2020). According to FAO (2021), the global output of fish, crustaceans, and mollusks was 117.8 million tonnes in 2019, a less than 1% decline compared to 2018. In 2019, aquaculture production totaled 85.3 million tonnes, a 3.7% increase over 2018. In 2019, the overall first-sale value of total output was USD 406 billion, with aquaculture production accounting for USD 260 billion. Notably, Nile tilapia (*Oreochromis niloticus* L.) make up over 80% of aquaculture production in Sub-Saharan Africa (SSA) (Wachira *et al.*, 2021). The aquaculture business employs around 2.6 million people in Africa, with women making up a significant portion of those engaged in large-scale commercial farms (Satia, 2016). Africa's contribution to global aquaculture production remains low (~2.7%) (Halwart, 2020). Between 1995 and 2018, the region's output increased twentyfold, from 110,200 to 2,196,000 tonnes, with a compound annual growth rate of 15.55% (FAO, 2016; Halwart, 2020).

The Kenyan fish market is suffering from an inadequate fish supply from both natural (rivers, lakes, dams, and marine sources) and farmed fish sources. Compared to a global average of 20.5 kg/person/year, Kenyans' annual per capita fish intake has remained constant at about 4.5 kg. By 2030, the country aims to boost per capita fish consumption to 10 kilograms per person annually (Munguti *et al.*, 2023). Landings from Lake Victoria, the country's primary supply of freshwater fish, have been declining over time. Similarly, fish aquaculture harvests are insufficient to cover the shortage (Obwanga & Lewo, 2017). Fish farming in the Lake Victoria region uses an array of production technologies, including cages, ponds, and tanks, and varies in size (Obwanga *et al.* 2019). With the global decline of catch fisheries and population upsurge, aquaculture is projected to play a significant role in providing an adequate supply of fish in the market (FAO, 2018). According to Economic Survey by KNBS (2022), fish output fell from 146.7 thousand tonnes in 2018 to 146.5 thousand tonnes in 2019 (Table 1.1). Furthermore, in 2019, fish farming accounted for 12.8% of the country's fish output. From 15.3 thousand tonnes in 2018 to 18.5 thousand

tonnes in 2019, the tonnage of fish taken from this source grew by 20.9%. However, overall fish output increased in 2021, rising from 151.3 thousand tonnes in 2020 to 163.6 thousand tonnes. Freshwater fish landings increased by 8.5% to 136.3 thousand tonnes in 2021 (KNBS, 2022). Currently, the production gap in Kenya is largely filled by imported frozen tilapia from China, which has been found to be sold at 55% of the value needed for local producers to break even (1 kg of imported fish is on average USD 2.5 per kg, while the break-even selling price for local producers is USD 4.5) (Obiero *et al.*, 2019).

Table 1.1: Quantity and Value of Fish Landed in Kenya, 2015 – 2021

Quantity in	2015	2016	2017	2018	2019	2020	2021
Tonnes-Years							
Fish farming	8,656	4,952	12,356	15,320	18,542	19,945	20,293
Lake Victoria	109,902	98,666	92,727	98,150	90,743	88,223	94,349
Marine Sources	22,126	24,165	23,286	24,220	25,670	25,690	27,279
Others Lakes and Rivers	23,140	19,895	6,731	8,997	11,588	17,417	21,684
Grand Total	163,824	147,678	135,100	146,687	146,543	151,275	163,605
Value in KShs	24,546	24,426	22,957	25,555	23,700	26,214	30,318
Million							

Source: KNBS Economic Survey, 2022

Despite aquaculture's potential economic contribution, the industry faces significant challenges, such as profitability, product quality, and environmental sustainability (Sun *et al.*, 2016). Aquaculture's economic viability and ecological sustainability rely heavily on the type and quality of fish feed utilized (Arru *et al.*, 2019). Like other terrestrial agricultural systems, aquaculture primarily depends on nutrient supplies. Diets with adequate nutritional balance are essential for improving fish health and increasing fish productivity (Bandari, 2018). One of the main bottlenecks in the growth of aquaculture in Kenya is inadequate quality and affordable aquafeeds (Amankwah *et al.*, 2016). Fish feeds account for up to 80% of fish farm production expenses and are an important limitation in resource-constrained regions. Reducing feed consumption for a given production level is thus critical to achieving economic sustainability in fish farming. Feed is therefore crucial to the success of aquaculture development. Commercial

fish feeds are scarce and costly to most fish farmers, who survive on less than a dollar daily (Charo-Karisa *et al.*, 2013). In Kenya, fishmeal (FM) is the most commonly used protein ingredient in fish feeds. The FM is processed from the silver cyprinid (*Rastrineobola argentea*, locally known as “Omena”) and the Nile perch captured from Lake Victoria and the Indian Ocean waters. Because of the unpredictable supply and growing price trend of FM, aquaculture may not maintain itself (Muin *et al.*, 2017). According to Muin *et al.* (2017), a rise in FM's market price will indirectly raise farmed fish's production cost. The cost of FM has risen by more than 400% in the last decade (Belforti *et al.*, 2015). In 2015, the retail price of fishmeal in Kenya was USD 1.4/kg (Fiaboe and Nakimbugwe, 2017). The fluctuating state of fishery resources in fishing zones, overexploitation of fish stocks, the introduction of fishing quotas, and increasing pressure to use fish oils and fishmeal in other markets such as health, food supplements, and cosmetics could all be attributed to the limited availability and high prices of fishmeal (Mitra *et al.*, 2020).

1.2 Status of Aquafeed Production and Demand

A high-quality commercial aquaculture feed comprises various components that give a high quantity of digestible protein, energy, and critical nutrients. As a result, a sustainable, high protein feed component for aquaculture is required. The high expense of aquafeed, its low quality and scarcity continue to constrain aquaculture internationally (Pelletier *et al.*, 2020). In 2018, worldwide feed output reached 1.1 billion tonnes, a 3% increase over 2017, and a 2.5% yearly average growth rate for the previous five years (Alltech, 2019). In the same year, the total global aquafeed output was 40.1 million tonnes (Alltech, 2019). Notably, aquafeed total production for all aquaculture species is expected to expand by 75%, from 49.7 million tonnes in 2015 to 87.1 million tons in 2025. (Tacon & Metian, 2015). As a result, finding alternative, cost-effective protein sources is vital to satisfy the additional 37.4 million tons of aquafeeds anticipated by 2025. According to Jannathulla *et al.* (2019), the aquaculture sector uses more than 70% of worldwide fishmeal, despite aquafeeds accounting for only 4% of overall industrial feed output (900–1,000 Mt in 2018). The growing trend of aquaculture production, along with lower fish-in/fish-out ratios (0.63 in 2000 to 0.33, 0.22 in 2010 and 2015, respectively), illustrates the aquafeed sector's resilience to fishmeal substitution.

Kenya has about 14 fish feed providers (Opiyo *et al.*, 2018). There are eight local fish feed manufacturers and six fish feed importers among them. All fish feed importers supply floating pellets, but only five local enterprises manufacture them (Munguti *et al.*, 2014; Opiyo *et al.*, 2018). Furthermore, small-scale feed mills create sinking pellets (Opiyo *et al.*, 2018). Local fish growers believe that imported feed costs too much (between USD 1.2/kg and USD 2/kg) (Obwanga *et al.*, 2018). Floating pellets and mash feed are two types of fish feed, with the main protein constituents in these meals being fishmeal and soybean meal. However, the limited availability, high cost, and environmental consequences of using these resources are significant barriers to attaining optimal productivity, particularly for smallholder growers in developing nations (Abiodun, 2019; Gordon & Maurice, 2015; Katende, 2017; Nwokocha & Nwokocha, 2013; Ssepuuya *et al.*, 2017). As a result, there is an urgent need to enhance aquaculture production to fulfill the increasing demand for fish.

1.3 Alternative Feeds in Aquaculture

The availability of proteins for aquafeeds is an integral part of the aquaculture industry's sustainability since fishmeal (FM) is a limited resource. Several elements should be considered while contemplating alternative fish diets to ensure their technical, economic, and social sustainability. Technical considerations include protein content, the nutritional quality of proteins, the presence of anti-nutritional substances, and fish digestibility, among other parameters that influence physical fish growth. Economic and social factors include manufacturing costs, customer preferences, willingness to pay (WTP) and willingness to accept (WTA), sensory acceptability, and hedonic appraisal (Enes & Peres, 2015; Hardy, 2010). A suitable alternative protein source should be able to provide enough protein with the optimal amino acid balance necessary for fish to maintain development and health (Arru *et al.*, 2019). These alternate feeds should be less expensive than fish meal and soybean, easier to get, and abundant locally. Protein quality, functionality, availability, and cost are considered in selecting feed components, and their raw materials that can be substituted for one another (Tacon & Metian, 2015).

1.3.1 Plant and Animal Protein Sources

Numerous studies have been conducted to replace or lower the inclusion amount of FM in aquafeeds and explore suitable alternative protein sources. Plant protein sources such as soybean meal, maize gluten meal, and soy protein concentrate, as well as mushroom by-products, have

been intensively explored as potential FM replacement elements in fish feed (Katya *et al.*, 2014). Plant proteins have the potential to be used as alternative diets in aquaculture. However, they have anti-nutritional characteristics, a high quantity of fibre and non-starch polysaccharides, an insufficient fatty acid (FA) and amino acid profile (Gay *et al.*, 2012), low palatability (Gatlin *et al.*, 2007), and impaired fish intestinal enterocyte integrity (Ferrara *et al.*, 2015). Soybean production has been linked to deforestation, soil erosion, eutrophication, significant pesticide use, biodiversity loss, and a massive CO₂ footprint (van Huis, 2015). Meat and bone meal, chicken by-products, blood meal, hydrolyzed feather meal, and other animal protein sources have also been employed (Hatlen *et al.*, 2014; Psoufakis *et al.*, 2020). However, due to the socio-cultural orientations of some communities and competition from the livestock and human feed industries, some of these materials have earned low acceptance ratings, making them inaccessible and unsustainable (Ogello *et al.*, 2014).

1.3.2 Insect-Based Meals

Because the majority of commercial fish species in aquaculture are either carnivorous or omnivorous, it is critical to locate a sustainable and eco-friendly protein supply that is abundant, low in cost, and has high energy conversion potential, such as insect protein (Henry, 2015; Xiao *et al.*, 2018). As a result, efforts have been undertaken to create alternate protein sources for aquafeed processing, with numerous insect species now being marketed as alternative fish feed (Van Huis *et al.*, 2013; Nugroho & Nur, 2018). In comparison to fishmeal, insects are appealing and alternative protein source in aquaculture feed. Furthermore, they have no harmful influence on marine ecology (Hashizume *et al.*, 2019).

Insect meals have recently piqued the curiosity of many scholars. According to research, insects can be successfully employed in fish diets (Barroso *et al.*, 2014; Henry *et al.*, 2015). They are prospective protein and fat sources. Most fish species eat insects naturally, but their contribution to domestic fish production is negligible (Govorushko, 2019). According to Sánchez-Muros *et al.* (2014), there are around one million known species of insects, with just 20% recognized and characterized, demonstrating the variety and potential of these components to replace fish meal. The European Commission has approved the use of insect meals in aquafeed [Reg. (EU) 2017/893], eliminating the feed prohibition on insect-derived processed animal proteins (PAPs) for farmed fish (Tan *et al.*, 2018). The regulation specifies the seven authorized insect species

black soldier fly (BSF) (*Hermetia illucens*), common housefly (HF) (*Musca domestica*), yellow mealworm (MW) (*Tenebrio molitor*), lesser mealworm (*Alphitobius diaperinus*), house cricket (*Acheta domesticus*), banded cricket (*Gryllodes sigillatus*), and field cricket (*Gryllus assimilis*). As well, it has defined the permitted rearing substrates for rearing insects (Gasco *et al.*, 2020; Madau *et al.*, 2020).

Recently, there has been a rise in the number of research contributions on the use of insect meal (IM) in aquafeeds (van Huis, 2013; Lock *et al.*, 2016; Borgogno *et al.*, 2017; Magalhaes *et al.*, 2017; Belghit *et al.*, 2018a, 2018b, Biancarosa *et al.*, 2019). Previous research has shown that aquaculture's insect-based protein meals may be utilized as a more sustainable alternative to traditional protein (fish or plant protein meals) (Gasco *et al.*, 2016; Henry *et al.*, 2015). Insects have an exceptional ability to improve low-quality organic material, require little water and cultivable area, and generate little greenhouse emissions (van Huis, 2013). The transition to insect-based feed opens up chances for a circular economy, improving environmental cleaning services by reusing biowaste and lowering greenhouse gas emissions (Ermolaev *et al.*, 2019; Mertenat *et al.*, 2019; Pang *et al.*, 2020; PROteINSECT, 2016). The use of insects as a feed source is known to lower economic and environmental expenses because they may be fed by-products and need no infrastructure or resources (Sealey *et al.*, 2011). Because of their high nutritional content, insect meals are ideal for feed applications. They also have a low water footprint and need little land (Tschirner and Kloas, 2017; Surendra *et al.*, 2016; Makkar, 2017).

According to Goal 14 of the Sustainable Development Goals, insect meal is also a very ecologically-friendly source of nutrition. The emerging insect sector, which is likely to become a significant component of the circular economy, supplies animal protein through a sustainable production process with low-value inputs, high-value outputs, and little environmental effect (Dicke, 2018). An economical, ecologically sensitive, and sustainable aquaculture is critical to addressing the world's growing food needs. This research looks at the use of Black Soldier Fly Larvae (BSFL) in aquaculture in Kenya. BSFL is one potential alternative insect-based aquafeed ingredient. The nutritional composition of BSFL is mostly determined by the organic substrate's content (Liland *et al.*, 2017). BSFL constitute 38.5–62.7% crude protein (CP), 14.0–39.2 % fat and 5282 kcal/kg of gross energy on dry matter (Liland *et al.*, 2017). Thus, BSFL meal is crucial

in meeting the nutritional requirements of Nile tilapia which grows well when fed on quality feeds of between 28–40 % CP depending on the stage of development (Henry *et al.*, 2015). However, little has been done on its ideal inclusion levels in Nile tilapia diet, considering its implication on socio-economic efficiency, implying its acceptability and cost-effectiveness. The study is intended to aid in bridging knowledge across research areas and produce a research agenda for understanding and directing the adoption of BSFL as an alternate feed in aquaculture. This study contains stakeholder opinions on the adoption of BSFL in aquaculture to understand the drivers of BSFL acceptability in aquaculture.

1.4 Statement of the Problem

Feed is the most crucial input in a fish farming operation, accounting for 40-80% of the Total Variable Cost (TVC) of output, depending on the farming type (Chia *et al.*, 2020). The cost of feed and its use is therefore critical in aquaculture production. The availability and accessibility of standardized cost-effective fish feeds are required to sustain Kenya's prosperous aquaculture business. The high feed cost for fish farmers means that fish feed is expensive and difficult to get, making aquaculture operations unsustainable. For the United Nations Sustainable Development Goals (SDGs) of eliminating hunger, food insecurity, and malnutrition (SDG 1), eradicating poverty (SDG 2), and conserving life below water to be met (SDG 14), immediate action is needed. This call for urgent action has pioneered research into low-cost alternative ingredients.

Traditionally, the fishmeal has been the primary feed for fish production. However, the global shortage of fishmeal and growing demand for livestock and poultry production are projected to lessen aquaculture's reliance on it as a feed. A locally manufactured feed that employs a more cost-effective ingredient, with a sustainable supply and a socially-acceptable production than the fishmeal is, therefore, a welcome intervention to address this issue while improving production efficiency. Insects are presently being promoted as food and feed. Researchers have recently used insect-based meals as an alternative to fish meals. In aquaculture production, Black Soldier Fly Larvae (BSFL) meal can be used in place of fish meal. However, information on the socio-economic efficiency of BSFL as a fish feed is scanty in Kenya. This research aims to assess the socio-economic efficiency of BSFL meal as a fishmeal alternative in aquaculture production with a focus on Nile tilapia species.

1.5 Overall Objective

The overall objective of this study was to assess the socio-economic efficiency of Black Soldier Fly Larvae (BSFL) meal as a substitute for fishmeal in aquaculture production in Siaya, Kisumu and Homabay Counties, Kenya.

1.6 Specific Objectives

1. To determine the technical efficiency of BSFL meal in aquaculture production.
2. To assess the economic efficiency of BSFL meal in aquaculture production.
3. To evaluate the acceptability of BSFL meal in aquaculture production.

1.7 Research Questions

Based on the above specific objectives, the following research questions were addressed:

1. What is the level of technical efficiency of BSFL in aquaculture production?
2. What is the level of economic efficiency of BSFL in aquaculture production?

1.7 Hypothesis

Based on specific objective three, this study tested the following hypothesis:

H₀: BSFL is not acceptable in aquaculture production.

This hypothesis was guided by the following sub-hypothesis;

H₀₁: Perceived ease of use has no positive and significant influence on farmer attitude to use BSFL.

H₀₂: Perceived ease of use has no positive and significant influence on farmer intentions to use BSFL.

H₀₃: Perceived usefulness has no positive and significant influence on farmer attitude to use BSFL.

H₀₄: Perceived usefulness has no positive and significant influence on farmer intentions to use BSFL.

H₀₅: Attitude has no positive and significant influence on farmer intentions to use BSFL

H₀₆: Perceived ease of use has no indirect positive and significant influence on farmer intentions to use BSFL.

H₀₇: Perceived usefulness has no indirect positive and significant influence on farmer intentions to use BSFL.

1.9 Justification of the Study

Identifying cost-effective fish diets is one issue facing Kenya's aquaculture production today. Insects have been recognized as a cost-effective, stable, and sustainable source of protein and other nutrients for food and feed to attain long-term food and nutritional security. Among insect species, BSFL has the most significant commercial potential for use as a protein source for feed (Komi & Nakimbugwe, 2014).

The findings on the technical efficiency of BSFL meals will inform policymakers on the use of formulated BSFL diets as a source of protein components in aquaculture. The findings of the economic efficiency research will provide farmers with information on fish meal feed replacement diets to utilize to decrease costs and optimize profit. The results will enable farmers to switch to a feed that will increase their returns and profit margins from fish farming. These findings will also improve investor confidence because there will be a high demand for the product with the potential to replace conventional feed.

On the social efficiency aspect, the findings from aquaculture farmers' perceptions about the use of BSFL meal products in aquaculture production will give insight into farmers' desire to embrace BSFL for fish production. The findings of the intention to accept analyses are anticipated to provide governments and commercial firms with insights that may be utilized to develop ways to promote the acceptability of using insects to feed fish.

Furthermore, this research intends to contribute to the Sustainable Development Goals (SDGs) of eliminating poverty, ending severe hunger, providing decent employment and economic development, and promoting responsible consumption and production. It will also help to achieve the aims of the Agricultural Sector Transformation and Growth Strategy (ASTGS) and Kenya's Big 4 Agenda for enhancing food and nutrition security. Finally, the study's findings will add to the current literature on BSFL meal production and create data and knowledge on the use of BSFL meal to boost not just Nile tilapia output but also aquaculture productivity in the nation and internationally.

1.10 Scope and Limitation of the Study

This study aimed to investigate the technical, economic, and social efficiency of employing BSFL meal as an alternative protein source in Nile tilapia production. Both time series and cross-sectional data were collected for the study. The study was limited to the riparian counties of Kenya's Lake Victoria area, rather than the entire country. Technical efficiency entailed measuring the growth performance parameters in feed replacement diets with Feed Efficiency (FE) and Feed Conversion Ratio (FCR) as the main indicators. Economic efficiency entailed the evaluation of the economic profit index (EPI), economic conversion ratio (ECR), and incidence cost (IC) of BSFL meal in an experimental pond. The experiment was conducted in one location (KMFRI, Sangoro Station) and not in all the locations in the area of study, which could affect the results because of the difference in climatic conditions and pricing of ingredients. Since the experimental data were obtained from one location, this may have limited application and generalization for the whole riparian counties. For social efficiency (acceptance), the study examined the awareness, perceptions, attitudes, and intention to accept BSFL meals by pond and cage farmers using a cross-sectional survey. The study also evaluated stakeholder consensus as part of the acceptability study. The use of an online platform for Delphi study to elicit stakeholder opinion has both advantages and disadvantages in terms of the potential to maximize coverage from diverse stakeholder groups given limited resources, as well as weaknesses in the collection of relatively superficial information using a survey-type approach, which can have limited response rates in specific groups and the potential for bias. To overcome these limitations, the study on stakeholder's opinion evaluation should be viewed as a scoping investigation. Finally, while BSFL has numerous potential advantages, the current study mainly looked at application in food security as a fish feed, specifically in Nile tilapia production.

1.11 Operational Definition of Terms

Alternative Feed: This is a feed that has not been used regularly in Nile tilapia production. In this study, the BSFL meal is considered an alternative feed.

Conventional Feed: This is a feed that has traditionally been used in commercial animal production. In this study, FM is considered a traditional feed.

Technical Efficiency: It is the ability of BSFL meal and FM to produce the maximum possible yield in Nile tilapia production. In this study, technical efficiency refers to the input-output relationship in aquaculture production and is captured through the fish growth performance parameters including Feed Efficiency and Feed Conversion Ratios.

Economic efficiency: Is the degree or ability of a farmer to produce a given level of production at the least cost (Farrell, 1957). In this study, it is used to mean the ability of aquaculture farmers to employ a cost-minimizing combination of farm inputs while producing the maximum possible Nile tilapia output, given the available technology.

Social efficiency: Is the best allocation of resources in society, considering external and internal costs and benefits. This study operationalizes social efficiency capture aquaculture pond and cage farmers' awareness, perceptions, attitudes, and intention to use BSLF feed in Nile tilapia production.

Intention to Use: The readiness of pond and cage farmers to adopt the use of BSFL meal in improving Nile tilapia production.

Pond-hapa: A *hapa* is a cage-like rectangular or square net impoundment placed in a pond to confine fish.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of Black Soldier Fly (*Hermetia illucens* L.)

Originally endemic to the subtropical and warmer temperate temperatures of the Americas, the Black Soldier Fly (*Hermetia illucens*), a Dipteran of the Stratiomyidae family, is now widespread throughout the world from latitude 46°N to 42°S (Makkar *et al.*, 2014). BSFL are naturally present in the faeces of pigs, cows, and chickens, but they may also be found on organic wastes such as vegetable waste, catsup, carrion, and fish offal. The larvae are thought to contain natural antibiotics (Newton *et al.*, 2008). BSF larvae crushed (also known as BSF larvae meal, BSF prepupae meal, and BSF maggot meal) are used live, chopped, dried, or crushed. Figure 2.1 shows the diagram of dried BSFL



Figure 2.2: Dried Black soldier fly larvae

2.1.1 Nutritional Profile of Black Soldier Fly

Fish requires diets with 30-55% crude protein and an adequate amino acid supply to meet their optimal growth needs (Henry *et al.*, 2015; Gomez *et al.*, 2019). The insect's stage of development, the type of food it is fed, and the conditions of its rearing affect the crude protein level of insect meal. Figure 2.2 shows the chemical composition of BSFL.

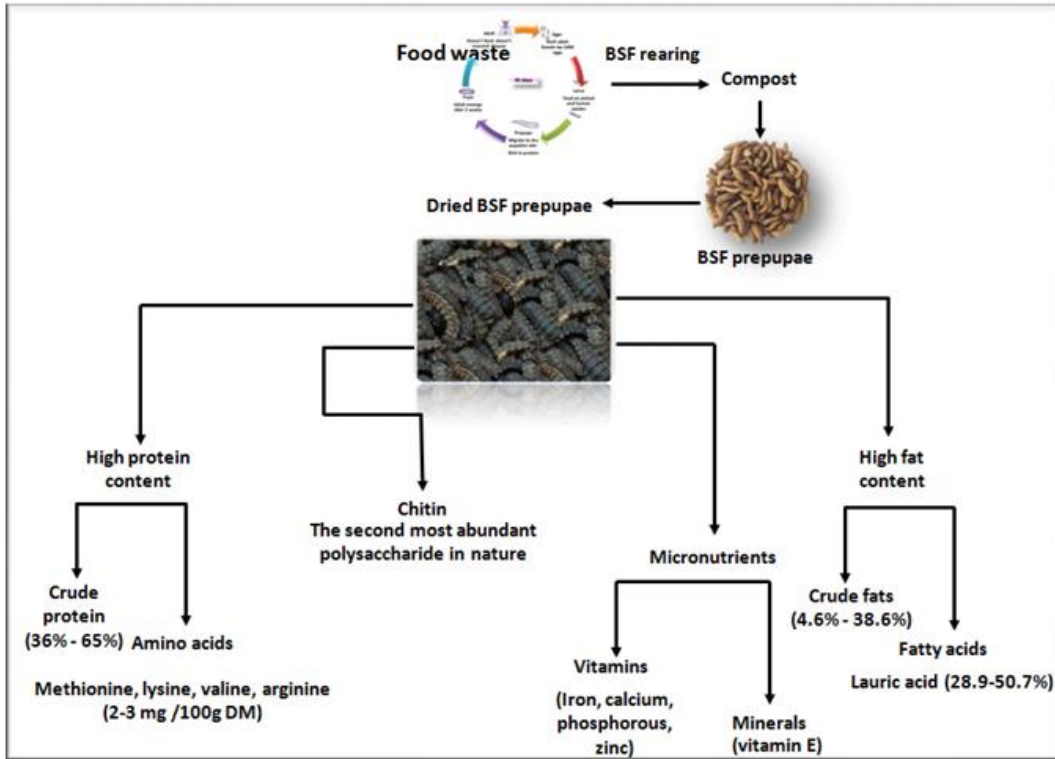


Figure 2.2: Chemical composition of Black Soldier Fly Larvae
Source: Abd El-Hack *et al.*, 2020

Amino acid content and digestibility also vary accordingly (Nogales-Mérida *et al.*, 2019). The Black Soldier Fly Larvae (*Hermetia illucens* L.) have good amino acid and fatty acid profiles for inclusion in animal diets and they are high in proteins (42.1 to 56.9% of the defatted meal, respectively), lipids (19-37%) (Makkar *et al.*, 2014; Smetana *et al.*, 2019). Protein and lipid levels in the BSFL are acceptable (307.5-588.0 gkg⁻¹ and 113.0-386.0 gkg⁻¹, respectively) (Caligiani *et al.*, 2018). It is approximately 90% digestible, has a high metabolizable energy content (20–24 MJ/kg), and a crude protein concentration of 38.0–60.4%, which is comparable to fishmeal (60.5–65%) and soybean (42.0–47%) (Arango Gutierrez *et al.*, 2004). Lysine, valine, and arginine biomass levels in black soldier fly larvae have all been shown to be between 20 and 30 g/kg DM., with an overall incidence of essential amino acids above 55% (Spranghers *et al.*, 2017). Table 2.1 summarizes a comparison of alternative protein sources in fish feeds to black soldier fly according to their mineral values.

Table 2.1: Comparison of protein sources according to their mineral values

	Black Soldier Fly	Mealworm	Soybean	Fishmeal
Iron(mg/kg)	100-630	9.61-245	92.9-919	81-715
Zinc(mg/kg)	42-300	33.8-117.4	41.4-77.0	56-381
Magnesium (mg/kg)	2100-5610	620-2027	2550-4940	700-4000
Calcium (mg/kg)	5360-61620	156-435	1600-4660	11800-80100
Phosphorus (mg/kg)	6800-13220	2640-7061	5640-7660	1530-43400
Sodium (mg/kg)	890-2500	225-3644	60-1090	3200-19800
Potassium (mg/kg)	10200-18790	3350-9480	20200-25200	330-15700
Copper(mg/kg)	7.5-34.25	8.3-20	9.0-18.7	3-108
Manganese (mg/kg)	190-730	3.2	29.7-70.8	3-37

Source: Hawkey *et al.*, 2021; Nairuti *et al.*, 2021; Alfiko *et al.*, 2022; Mabelebele *et al.*, 2023

2.1.2 Black Soldier Fly Rearing Substrate

The nutritional profile of BSFL depends on the type of substrate used to rear it. For adequate larval development, BSFL requires substrates that include at least 10% protein, 2% fat, and 2% minerals (Spranghers *et al.*, 2019). In a 1:2 protein- carbohydrate ratio, carbohydrates and total proteins should make up 50% of total dry matter for optimum larval development (Barragán-Fonseca *et al.*, 2018). Ites *et al.* (2020) found that in a modular system maintained at 27°C and 60–70% humidity, BSF larvae had a feed conversion ratio of 4.16 kg for 1 kg of dry larval biomass on environmentally and economically efficient feed, 7.25 kg of brewery grains, 6.28 kg for potato peels, and 14.5 kg for 1 kg of dry larvae on expired food. Another study found that the protein content of BSFL was highest when given organic material from human food (583 g/kg sample), while it was lowest when fed fruit surplus (307 g/kg sample). Chicken droppings (480 g/kg sample) and brewery byproducts (529.6 g/kg sample) also had a substantial amount of larval protein (Nogales-Mérida *et al.*, 2019).

Substrates made from organic wastes are appropriate in commercial large-scale insect feed production (Shumo *et al.*, 2019). Black soldier fly (BSF) larvae, which may be used as a source of protein in animal feed, can be raised in waste. The BSFL can convert organic waste into biomass rich in nutrients suitable for animal feed, which might result in more sustainably produced food. Black soldier fly larvae have been artificially raised in captivity using a variety of organic wastes. These include the excrement of humans, palm kernel waste, pig liver, kitchen waste, rendered fish, and cattle manures from large, confined animal feeding operations (Hem *et al.*, 2008; Canary, 2009; Diener *et al.*, 2011a; Diener *et al.*, 2011b; Popa & Green, 2012; Lalander *et al.*, 2013; Kalová and Borkovcová, 2013; Nguyen *et al.*, 2013; Zhou *et al.*, 2013; Banks *et al.*, 2014; Nguyen *et al.*, 2015). When compared to substrates like manure, catering waste, or previously consumed foods containing meat and fish, which are prohibited because insects are regarded as "farmed animals," the European Food Safety Authority (EFSA) has endorsed the use of fruit and vegetable substrates as feed for insect production for having the highest potential of use. They pose a lower risk of transmitting zoonotic diseases to humans (EFSA Scientific Committee, 2015). Fruits and vegetables serve as a sustainable insect-rearing substrate because they include a significant amount of post-harvest waste and losses, as well as numerous byproducts of the fruit and vegetable processing industries (FAO, 2011, Kalová and Borkovcová, 2013; Nguyen *et al.*, 2015; Paz *et al.*, 2015). It is well known that BSFL can be used to break down a variety of organic waste streams, including animal manure (Xiao *et al.*, 2018), fruit and vegetable remnants (Nguyen *et al.*, 2013), animal manure (Meneguz *et al.*, 2018), and even some foods that are inedible, like coffee pulp (Diener *et al.*, 2009). According to Spranghers *et al.* (2017), raising BSF larvae on vegetable waste streams might produce high-quality insect resources for animal feed.

2.2 Empirical Review of Literature

2.2.1 Technical and Economic Efficiency of Partially Replacing Dietary FM with BSFL Meal in Nile Tilapia Production

In developing countries like Kenya, efficient input use is critical for long-term aquaculture production improvement, better profitability, and improved livelihoods. Technical efficiency is the output-to-input ratio (represented in this research by the fish growth parameters). In contrast, economic efficiency is the monetary representation of technical efficiency by attaching a price. It

thus implies that economic efficiency is the ratio of the value of the output divided to the value of the input. To achieve economic efficiency, technical efficiency is a necessary but not a sufficient condition.

Studies using novel aquafeed ingredients to replace fishmeal or oil have shown conflicting findings regarding species growth and economic efficiency. In general, available literature supports the feasibility of using insect meal in place of FM wholly or partially. Some fish feeding research (Belghit *et al.*, 2018; Cummins *et al.*, 2017; Dumas *et al.*, 2018; Elia *et al.*, 2018; Lock *et al.*, 2016; Magalhes *et al.*, 2017; Renna *et al.*, 2017) have shown that FM replacement with BSFL meal in aquafeeds is successful, while others have proved otherwise (Gasco *et al.*, 2016; Kroeckel *et al.*, 2012; St-Hilaire *et al.*, 2007). The growth performance and feed conversion of nursing Nile tilapia fingerlings with various levels of fishmeal replacement with BSF meal were comparable (Devic *et al.*, 2018).

Black soldier fly (BSF) pre-pupae meal inclusion in the diets of Nile tilapia fingerlings was investigated by Groenewald (2018) for its effects on growth performance, fillet yield, and feed quality. The study recommended a 5% BSFL meal inclusion level to maintain growth performance. Numerous studies have demonstrated that BSFL can enhance fish growth performance, digestibility, feed conversion ratio, and feed utilization efficiency alone or in combination with other components (Table 2.2). The least replacement, 6%, was achieved in *Oreochromis niloticus* using partially defatted BSFL (Toriz-Roldan *et al.*, 2019). On the other hand, *Danio rerio* (Lanes *et al.*, 2021), *Oreochromis niloticus* (Tippayadara *et al.*, 2021), *Cyprinus carpio var. Jian* (Zhou *et al.*, 2017) and *Salmon salar* (Belghit *et al.*, 2019) were shown to have a maximum replacement of 100%.

Table 2.2: Empirical review of literature on growth performance (technical efficiency measurements) of fish fed on BSFL

Fish tested on	Attribute/element tested	Recommended replacement levels	Country	Authors
Nile tilapia (<i>Oreochromis niloticus</i>)	Growth Performance, feed utilization and body composition	Up to 50%	Malaysia	Muin <i>et al.</i> (2017)
Yellow catfish (<i>Pelteobagrus fulvidraco</i>)	Growth performance, feed utilization and plasma parameters	20%	China	Hu <i>et al.</i> (2017)
Atlantic Salmon (<i>Salmon salar</i>)	Growth potential, nutritional utilization, liver health and fillet sensory parameter	100%	Norway	Belghit <i>et al.</i> (2019)
Pacific white shrimp (<i>Litopenaeus vannamei</i>)	Growth performance	Up to 20%	USA	Cummins <i>et al.</i> (2017)
Turbot (<i>Psetta maxima</i>)	Growth performance	33%	Germany	Kroeckel <i>et al.</i> (2012)
Nile tilapia (<i>Oreochromis niloticus</i>)	Growth performance	100%	Thailand	Tippayadara <i>et al.</i> (2021)
Atlantic Salmon (<i>Salmon salar</i>)	Growth and digestibility	200g/kg	Canada	Fisher <i>et al.</i> (2020)
Yellow catfish (<i>Pelteobagrus fulvidraco</i>)	Growth performance and immune index	25%	China	Xiao <i>et al.</i> (2018)
Japanese seabass (<i>Lateolabrax japonicus</i>)	Growth performance	Up to 64%	China	Wang <i>et al.</i> (2019)
Jian carp (<i>Cyprinus carpio var, Jian</i>)	Growth performance	Up to 50%	Laos	Li <i>et al.</i> (2017)
Climbing perch (<i>Anabas testudineus</i>)	Growth performance	30%		Vongvichith <i>et al.</i> (2020)
Rainbow trout (<i>Oncorhynchus mykiss</i>)	Fillet yield	50%	Italy	Bruni <i>et al.</i> (2018)

Source: Author's summaries from literature review (2022)

From an economic point of view, Sumbule *et al.* (2021) conducted an economic analysis to assess the influence of BSFL as an FM alternative in layer chick and grower diets on growth and economic returns. Dietary patterns that including more BSFL meal (>75%) showed favorable cost-benefit analyses and investment returns. The best-suited and most economical diets contained 25% and 100% BSFL meal, respectively. Similar to this, Onsongo *et al.* (2018) evaluated the impact of switching from soybean and fish meal to BSFL meals on the growth and productivity of broilers. When the birds were fed on the maximum concentration of BSFL meal, the cost-benefit ratio was 16.0% higher, and the return on investment was 25.0% greater than when they were reared on the normal diet, which was 19.0% more expensive.

Opong (2017) used a partial budget to assess the gains achieved by Ghanaian fish producers by switching from traditional feed to BSFL-based feed-in capture fisheries. The study found that using 14.6 kg of BSFL-based fish feed instead of 14.6 kg of conventional feed might result in a USD 0.87 savings for fish farmers. Similar to this, Rawski *et al.* (2021) looked at the environmental sustainability, financial viability, and gastrointestinal tract development of meals for Siberian sturgeons that replaced fish meal and fish oil with full-fat larvae feed (BSFL). The adoption of BSFL as an alternate feed ingredient in Siberian sturgeon diets results were promising. The profitability of BSFL in the diet reached between 10% to 15%, whereas sustainability progressed with an increasing percentage of BSFL. Similarly, Kishway *et al.* (2022) evaluated the economic viability of substituting fish meal protein in the diets of Nile tilapia with partially defatted black soldier fly larval feed. The study found that Nile tilapia can replace partially defatted BSFL meal for fishmeal by up to 100% and that BSFL is a cost-effective strategy for fish farming since it reduces Nile tilapia feed expenditures. Table 2.3 summarizes other empirical review of literature on economic efficiency measurement of fish fed on BSFL.

Table 2.3: Empirical review of literature on economic efficiency measurement of fish fed on BSFL

Study	Country	Findings
Stejskal <i>et al.</i> , (2020)	Czech Republic	Using BSFL in the diets of Eurasian Perch (<i>Perca fluviatilis</i>) Juveniles at the price level of 3.5 €/kg resulted in an almost 11 cent per kg price increase per 5% incorporation
Rawski <i>et al.</i> , (2021)	Poland	Using BSFL in the Siberian Sturgeon Farming at the price level of 3.00 €/kg resulted in a feed price increase of 7.5 € cents/kg per each 5% of BSFL inclusion.
Odhiambo <i>et al.</i> , (2022)	Kenya	Replacing fishmeal with BSFL meal (Ksh 52.1 per kg) at 100% was cost-effective and reduced the cost of feeding Nile tilapia by 26.8% (economic savings of Ksh19.09 per kg)
Limbu <i>et al.</i> , (2022)	Tanzania	The cost of BSF ingredient was 0.86 USD per kg compared to 1.51 USD per kg for FM, which resulted in 20.50% and 27.34% cheaper diets for the BSFL meal replacement at 75% and BSFL meal replacement at 100 %, respectively. The formulated diets cost decreased as the levels of BSF-L replacement increased in feeding Nile tilapia fry

Source: Author's summaries from literature review (2022)

Assessing FM replacers in Nile tilapia diets has been limited from economic point of view in favour of biological and nutritional considerations. Current studies of this kind either focused on different fish species or as a poultry feed, with very few studies on *Oreochromis niloticus*. This work contributes to the knowledge on using BSFL at various inclusion levels in *Oreochromis niloticus* rearing in hapas reared in earthen ponds. Also, there are few empirical studies on the economic efficiency of BSFL in fish production in Kenya. Therefore, a careful investigation of the technical and economic efficiency of BSFL in aquaculture production would benefit producers and policymakers in decision-making in Kenya and indicate the optimal levels of

BSFL that would increase fish productivity at least costs. Therefore, the goal of this work is to bridge this knowledge gap.

2.2.2 Farmers' Awareness of BSFL

Using BSFL feed instead of FM is an ingenious strategy for sustainable fish farming. Previous studies (Allegretti *et al.*, 2018; Magalhes *et al.*, 2017; Nyakeri *et al.*, 2017; Renna *et al.*, 2017; Rumpold & Schlüter, 2014), indicate that BSFL meal has a promising potential of replacing commercially available feed components. There has been a rise in BSFL research and industrial-scale production as feed ingredients in recent years (FAO, 2013; Wang & Shelomi, 2017). In Europe and the United States, BSFL is permitted for use in animal feed, primarily for aquaculture (Meneguz *et al.*, 2018, Tomberlin & Cammack, 2017). Black soldier fly larval meal production in 5m × 10m buildings can produce 2 tonnes of fresh larvae for USD 0.20 per kg of dry matter, which can be sold to farmers and feed processing businesses for USD 0.90 per kg of dry matter (Fiaboe & Nakimbugwe, 2017).

More profound knowledge of the factors impacting farmers' awareness of the use of BSFL meal in aquaculture is required to develop suitable policies and programs to deal with the low fish yield. This is crucial for improving the adoption process since it focuses on the aspects that can increase both awareness and acceptance of BSFL in aquaculture. Subsequently, Wilkinson *et al.* (2020) used an online survey to examine Australians' knowledge and acceptability of eating insects. Sixty-eight percent of the 820 participants in the online survey had heard of entomophagy. In the United Kingdom, Spartano & Grasso (2021) evaluated willingness to try (WTT) eggs produced from insect fed hens. The study found that only 17% of participants knew that insects can be used as a source of animal feed, yet most customers were WTT (72%). Moreover, Ankamah-Yeboah *et al.* (2018) found that only few consumers were concerned about the type of feed used to raise fish, with just 23% of those surveyed expressing negative sentiments regarding fish raised on insects rather than conventional feed. Piha *et al.* (2018) explored how consumer awareness impacts willingness to buy (WTB) insect-based food products. According to the findings, the impacts of different forms of information and food neophobia on WTB were primarily indirect and mediated by general attitudes. Table 2.4 summarizes some of the studies that have examined the use of BSFL as an insect-based feed in Kenya.

Table 2.4: Summary on Studies on Farmers' Awareness of BSFL as an Insect- based feed in Kenya

Study	Findings (level of awareness)	Research gap
Chia <i>et al.</i> (2020)	Results of the study revealed that over 70 and 80% of poultry and fish farmers, respectively, were aware that insects can be used as a feed ingredient.	This study focused 100% on poultry and fish farmers and did not involve other stakeholders who are likely to be impacted in some way.
Okello <i>et al.</i> (2021)	The results revealed that 70% of the farmers were aware of the insect-based feed attributes,	The study was focused on chicken farmers only.
Khaemba <i>et al.</i> (2022)	The results revealed that 65% of the consumers were aware of the benefits of integrating insect protein in poultry feed	This was a cross-sectional survey on poultry consumers' awareness and did not capture fish farmers awareness.
Odinya <i>et al.</i> (2022)	The findings indicated that only 11% of the dairy farmers were aware of the use of insects as an alternative source of livestock fee	The study was specific to dairy farmers only.
Bulinda <i>et al.</i> (2023)	The study found that about 44% of the farmers were aware of the use of black soldier fly in the animal feed industry, of which 46.72% were female, and 41.59% were male	The study used a cross-sectional survey to examine the factors influencing farmer awareness of BSFL and its usefulness as ingredient in livestock feed (poultry and pig) from a gender perspective.

Source: Author's summaries from literature review

Studies on using BSFL feed in aquaculture in Kenya are scanty. Most studies on awareness of BSFL as insect-based feed have been conducted in the European context and focusses on raising awareness of insects as food rather than feed. Therefore, this study bridges this knowledge gap.

2.2.3 Farmers' Perceptions, Attitudes, and Intentions of using BSFL

Insects have not yet been fully embraced in the commercial manufacture of aquafeeds. It is crucial to ascertain the current attitudes and acceptance of the targeted fish processors, fish dealers, and fish farmers before introducing insects as a new component since technological factors impact their adoption decisions. According to previous studies, BSFL meal has promising

potential to replace currently existing commercial feed components (Rumpold & Schlüter, 2014; Renna *et al.*, 2017; Nyakeri *et al.*, 2017; Magalhães *et al.*, 2017; Allegretti *et al.*, 2018).

Opping (2017) evaluated the acceptability and economic viability of fish feed in Ghana that is based on the Black Soldier Fly meal. According to the survey, fish farmers perceived BSFL feed as beneficial and were willing to pay an average of USD 32.18/20 kg. Similarly, Domingues *et al.* (2020) investigated the factors influencing consumer willingness to accept the use of insects to feed fish in Brazil. Perceived benefits were associated with a higher likelihood of accepting the use of insects to feed fish. Heloisa *et al.* (2020) evaluated the factors influencing consumer willingness to accept the use of insects to feed fish, cattle, pigs, and poultry in Brazil. A wider acceptance was found for the use of insects to feed fish. According to the results of logistic regression models, positive attitudes were associated with a higher likelihood of embracing the use of insects to feed chickens, pigs, cattle, and fish. Higher likelihood of using insects to feed fish was associated with perceived benefits. In another study by Mulumpwa (2018), it was found that the Malawian fish industry may turn around and become more productive if insect meal is introduced to fish feed in place of soybean and fish meal. The inclusion of insects in fish feed was found to have the potential to increase fish intake per capita in Malawi, thereby enhancing food security.

Verbeke *et al.* (2015) evaluated the perceived benefits and risks of using BSFL in fish feed using a five-point Likert scale. On a Likert scale, farmers in the experiment rated 14 benefit and risk statements from (1) strongly agree to (5) strongly disagree. The study found that the benefit and risk statements' composite overall mean evaluations were 3.71 and 3.04, respectively. Popoff *et al.* (2017) investigated public perceptions on the use of insect-derived components in Scottish salmon meals in the United Kingdom. The study examined the perspectives of salmon farmers, feed manufacturers, and fish dealers. Consumer opinions about the utilization of insect meals were shown to be positive. According to the study, feed manufacturers and salmon producers are generally open to using insect meals as long as the feeds are reliable and safe. It also recommended that additional information might raise awareness and boost the possibility of individuals accepting insect-based feed (IBF).

Three hypotheses were put forth by Bazoche and Poret (2016) to examine the willingness of consumers to choose products from animals fed with insects, to characterize the associations between consumers' acceptance of insects as food and food neophobia, disgust, and personality traits, and to assess the influence of positive information on consumers' willingness to make such decisions. The results seemed to suggest that consumer decision-making may be influenced by awareness of the environmental impact of aquaculture feeding systems. With awareness campaigns about the harmful effects of traditional feeding techniques, the desire for animal feeding with insect meals might be increased.

Baldi & Mancuso (2015) investigated future customer attitudes toward eating fish grown from insect meals as a strategy for improving the sustainability of the aquaculture farming system. The study focused on Italian fish consumers, and the findings revealed that consumers were sensitive and willing to test a new innovative product.

In Uganda, Ssepunya *et al.* (2019) conducted surveys of 208 fish farmers and 71 traders and processors of fish feed. Only 44.8% of fish farmers and 8.6% of feed traders and processors had ever used insects, despite the fact that the majority of fish farmers (94.9%) and feed traders or processors (91.5%) were willing to do so. The study concluded that boosting mass insect production will increase apparent readiness to utilize insects for feeding fish.

Fish producers in Kenya are open to embracing BSFL as an alternative feed in their production (Chia *et al.*, 2020). Komi & Nakimbugwe (2014) observed that the Black Soldier Fly (BSF) had tremendous potential, absence of nuisance, and conversion to organic fertilizer and animal protein under the INSFEED project on integrating insects in poultry and fish feed in Kenya and Uganda. 506 farmers, business owners, lawmakers, and scientists received training in raising insects for animal feed, while 25,388 listeners responded to radio-based awareness campaigns. The study demonstrated the feasibility of producing insect-based feeds for cost-effective, environmentally friendly chicken and fish production. Table 2.5 summarizes some of the studies that have been undertaken in Kenya on farmer's perceptions, attitudes and intentions of using BSFL as insect-based feed in Kenya. By focusing on the factors that influence farmers' intentions to adopt BSFL in aquaculture production, the current study fills a specific gap in the literature.

Table 2.5: Summary of Studies on Farmers' Perceptions, Attitudes, and Intentions of using BSFL as insect-based feed in Kenya

Study	Findings (perceptions, attitude and intentions)	Research gap
Waithanji <i>et al.</i> (2020)	Gendered patterns in knowledge, attitudes and practices were more distinct among poultry smallholder farmers than pond fish farmers interviewed.	This study was purely qualitative through focus group discussions and focused on both poultry and pond fish farmers from a gender perspective. The findings were thus generalized
Kinyuru & Ndung'u (2020)	The study identified social and psychological barriers to insect's acceptance as food and feed	The study was generalized on use of insect as both and feed and was mainly a review study.
Okello <i>et al.</i> (2023)	Farmers were willing to pay premium prices ranging between USD 0.35 and USD 3.45 for insect-based feed in the form of either pellets or mash, feed explicitly labelled as containing insects, insect protein feed mixed with soybean and fishmeal and dark-colored feed.	The study used a cross-sectional survey approach and focused on farmers' willingness to pay for attributes of insect-based commercial chicken feed
Harriet <i>et al.</i> (2021)	Consumers were willing to pay for meat derived from chicken fed on insect-based feed	The study used a cross-sectional survey approach and focussed on consumers preferences and willingness to pay for meat derived chicken fed on insect-based feed (including BSFL)
Morris <i>et al.</i> (2022)	The study found that 75.6% of youth were willing to farm and edible insects as a source of income	The study mainly focused on the youth's as the respondents and did not specify the category insect-based feeds in the study

Source: Author's summaries from literature review

2.2.4 Stakeholders' Perspectives on the Use of BSFL in Aquaculture

Any new product or service development process must include stakeholder interaction to gather data, thoughts, and opinions. To further the development of insect-based protein as sustainable aquafeeds, stakeholder engagement is crucial for establishing future objectives and targets for research, policy, and producer innovation. Therefore, obtaining consensus for successful policy

creation and implementation depends on stakeholder engagement. The process requires sharing and comprehending competing stakeholder points of view to prevent conflicts and advance equitable and long-term outcomes (Brown *et al.*, 2020). Insect meals like BSFL have recently attracted the attention of researchers, and studies have demonstrated that they can be successfully included in fish diets (Barroso *et al.*, 2014; Henry *et al.*, 2015). Therefore, the consensus among experts on the use and sustainability of such novel new feeds is necessary. Studies on expert consensus have been conducted in several fields. For example, animal welfare in agriculture (Rioja-Lang *et al.*, 2020), the viability and effectiveness of biosecurity measures on dairy farms (Shortall *et al.*, 2017), and the benefits of genetically modified crops (Lassoued *et al.*, 2020). However, there is limited study on insect-based feed in the aquaculture industry from a broad stakeholder perspective.

Italian trout and seabass farmers' use of insect meals as a feed component in the European setting was studied by Mulazzani *et al.* (2021). Interviewees included farmers, feed manufacturers, and manufacturers of insect meals. The results showed that feed price and feed conversion ratio (FCR) were the key factors influencing the adoption of the new feed. In a second study, Popoff *et al.* (2017) conducted interviews with a wide range of industry participants from the Scottish insect-feed-aquaculture value chain to gauge their awareness of, knowledge, and attitudes toward new feeding alternatives. The study found that to replace the current protein sources in feed successfully, a supply chain of consistent feed quality at a competitive price was required. Few studies have investigated stakeholders' perspectives on the emerging topic of using insects as feeds in African countries. Pomalegni *et al.* (2017) and Ssepuuya *et al.* (2019) in Benin and Uganda are some of the two recent studies that looked at stakeholders' perspectives on the growing issue of using insects as feeds.

Several studies have focused on the aquaculture stakeholder perspectives in different areas. For example, Chu *et al.* (2010) explored the perceptual disparities of aquaculture stakeholders in the United States and Norway and how their perceptions impact their decisions to support aquaculture development. Galparsoro *et al.* (2020) conducted a survey of 614 stakeholders, including members of the research community, the aquaculture industry, the government, conservation organizations, and associations for fishermen and educators, to determine the main

risks and obstacles limiting the development and growth of marine aquaculture, and the requirements and suggestions for overcoming these limitations. Similar to this, Weitzman and Bailey (2017) used the Q- methodology to examine the opinions of six stakeholder groups with interest in aquaculture—namely, the fish farming industry, the food industry, scientists, management, the wild capture fishing industry, and environmental organizations—about the eco-labelling of finfish aquaculture in Canada.

Exploring stakeholder perceptions as they relate to aquaculture and insect-based feeds is an emerging topic in the literature. Apart from the public and consumers' perceptions, the perspectives of the stakeholders, who implement the use of insect-based feeds in the farming practices are of particular importance. Understanding how key stakeholders understand and interpret the increasing link between aquaculture and insect-based feeds is important for industry development. Perspectives on stakeholder groups are valuable input for effective and sustainable aquaculture management (Steeves & Filgueira, 2019).

The acceptance of palm weevil larvae (*akokono*) as a food source and the viability of micro-farming this local edible insect as a supplement diet for infants and young children were the subjects of anthropological research by Laar *et al.* (2017). Interviews with 25 key local stakeholders were undertaken. According to the findings, stakeholders generally had positive perceptions of *akonono* as a nutritious meal. Stakeholders considered the larvae as farmable and were open to its domestication.

Greek delegates of an aquaculture conference were polled by Rumbos *et al.* (2021) to learn more about their opinions on the use of insect meal in fish diets. The study also examined the perspectives of nine Greek businesses involved in aquaculture and aquafeed on the creation and application of insect-based feeds in aquaculture. The study's results showed that more than half of the participating businesses supported adding insects to fish diets and were ready to put this innovation into practice. Other interested parties demanded further knowledge and insight into the use of insects in aquaculture.

In a study undertaken by Verbeke *et al.* (2015), 137 stakeholders from different agricultural sectors (including corporations in the animal and cattle industries, the government, consulting

firms, financial institutions, and research institutes) were surveyed about the use of insects in animal diets. Though regarded as less microbiologically safe than conventional feed, the insect-based feed was thought to be more sustainable and to have better nutritional content. The study's overall conclusions showed momentum for change in the use of insects as a novel component in animal feed.

The current study used an expert consensus to identify perceptions and drivers of BSFL sustainability in aquaculture in Kenya. According to the authors' knowledge, this is the first stakeholder analysis study with this objective in Kenya. Consensus in this study is defined as a high degree of agreement among stakeholders regarding specific outcomes of BSFL meal. The study focused on consensus because it is an important precursor to collective and equitable guidance within social, economic, policy and cultural systems (Larsen *et al.*, 2019). This study forms part of a larger body of works which identify the perspectives of a range of stakeholders concerning the use of insect-based meals in aquaculture.

2.3 Theoretical framework

This research was based on Production Cost and Technology Acceptance Model (TAM) theories.

2.3.1 Production Cost Theory

This study is based on the Production Cost Theory, which assumes that aquaculture farmers are rational and aim to maximize profits at the lowest possible cost. Farmers who generate the best output potential from available inputs are said to be efficient (Mukami, 2018). Production function relates physical output of production process to physical inputs or factors of production. The production function, therefore, describes a boundary or frontier representing the limit of output obtainable from each feasible combination of inputs. Technical efficiency is assessed using the production frontier as a benchmark. Technically efficient firms are those that operate along the frontier. Technical inefficiency is attributed to those who produce below the frontier (Coelli *et al.*, 2005).

Production factors are frequently categorized as fixed or variable in the short run. The law of variable proportions is studied when coupled with varying input proportions. When the quantity of inputs increases, so does the cost. As a result, this concept is also known as the law of increasing costs. The linear, quadratic, and log-linear (Cobb-Douglas, C-D) functions in aquaculture production require specific inputs to optimize profit. Land, seed, feed, labour, and capital are all inputs, while the output is the marketable fish or fingerlings. Although many inputs are used in most production processes, typically, costs are categorized into capital and labour. 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.

This study adopted the single input- output production function as in equation 2.1:

$$Y = f(X_1/ X_2, X_3 \dots X_n) \quad (2.1)$$

Where Y is the fish biomass harvested in Kg during the production cycle,

X₁ is the feed (variable input) used in fish production

X₂-X_n are the fixed inputs in fish production

2.3.2 Technology Acceptance Model

The Technology Acceptance Model (TAM) provides the foundation for the conceptual model of social efficiency used in this study. The theories of planned behaviour and theory of reason and action by Fishbein and Ajzen have undergone a notable and substantial change known as TAM (Fishbein & Ajzen, 1975; Ajzen, 1991). Davis (1989) developed the TAM based on rational choice theory and provides valuable guidelines for identifying the variables influencing users' acceptance of innovations (Castiblanco *et al.*, 2021). The TAM is the most extensively used model for the intention to adopt a technology due to its excellent predictive potential (Kumar *et al.*, 2018). As shown in Figure 2.3, attitudes toward a novel product or technology and subsequent behaviour when employing the technology are influenced by Perceived Usefulness (PU) and perceived ease of use (PEOU). According to Davis (1989), perceived ease of use is the idea that using technology doesn't need any effort on the user's part. Perceived Usefulness, according to Michels *et al.* (2021), is a person's belief that technology improves work performance. According to the TAM paradigm, PU and PEOU influence a person's intention to use technology and their actual adoption.

Furthermore, a person who believes technology is easy believes the technology is more valuable (Davis, 1989). Ulhaq *et al.* (2022) also noted that PEOU could operate via PU, indicating that a technology's perceived ease of use can make it more useful. Notably, according to the TAM framework, a fish farmer who perceives using BSFL as simple will be more likely to use it in fish production. Furthermore, if the farmer believes that using BSFL will help increase fish production output, they are more likely to adopt it. Additionally, a farmer perceives BSFL to be more beneficial if they think applying it is feasible, which is consistent with the earlier findings of Michels *et al.* (2021)

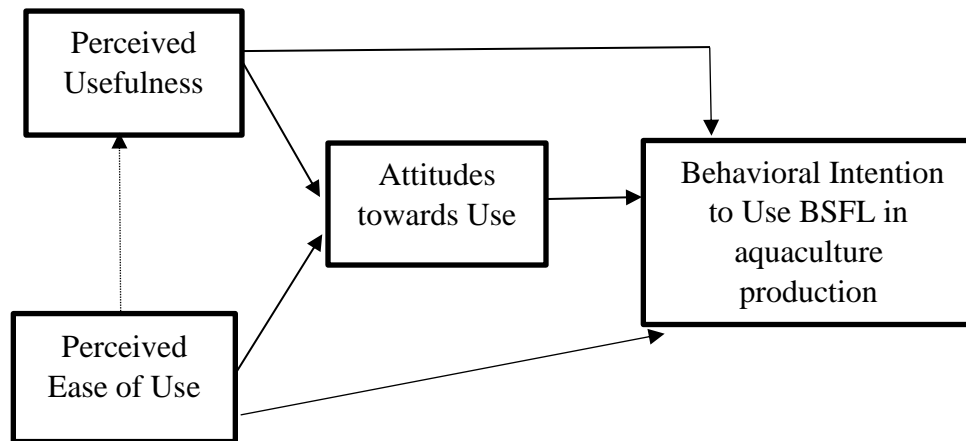


Figure 2.2: Research model showing a potential relationship between technological acceptability criteria and plans to utilize BSFL in fish farming

Source: Author, 2022

Attitude is an individual's negative or favorable sentiments toward the behaviour in concern (Fishbein & Ajzen, 1975). According to Kurkinen (2012), TAM views attitude as a mediator in the model. On the other side, perceived simplicity of use and perceived usefulness are significant indicators of attitude (Ducey & Coovert, 2016; Verma *et al.*, 2018). Accordingly, in the case of BSFL, if a farmer believes that BSFL is technically easy to use and using BSFL meal as useful, the farmer will form a favorable attitude towards BSFL meal.

In the TAM model, intention indicates how much a person tries to do a specific behaviour. Honkanen & Young (2015) noted that intention captures people's motivation to perform the behaviour and their likelihood of following through with it. A stronger intention for behaviour, in general, indicates that the behaviour is more likely to be practiced (Ajzen, 1991). Behaviour (actual use) is always after the behavioral intention and is connected to it. Chang *et al.* (2016) found that farmers' favourable sentiments toward water conservation might predict the implementation of water-saving programs. Perceived ease of use has been proven in earlier research by Aren *et al.* (2013) and Chen (2012) to impact intentions favorably.

Based on the research model in Figure 2.3, seven hypotheses were formulated as in Chapter One, sub-section 1.8.

The TAM has been used for agricultural research in several research areas, including precision agriculture (Michels *et al.*, 2021), acceptance of solar water pumps by smallholder farmers (Zhou & Abdullah, 2017), farmers' adoption of organic rice and integrated production (Sharifuddin *et al.* 2018; Silva *et al.* 2017) respectively, consumption of iodine biofortified foods (Mogendi *et al.* 2016), among others. However, few studies have used TAM in aquaculture-related studies (Obiero *et al.*, 2019; Ghorbani & Ghorbani, 2020).

2.4 Conceptual Framework

This defines the variables of research and how the independent variables influence the dependent variables. Technical efficiency, economic efficiency and acceptability of BSFL in aquaculture production depends on several factors including the farmer characteristics and production variables. Production variables modelled in the experimental set up include feeding management, fish genetic characteristics, water quality and prices of feed ingredients. Farmer's awareness and decision on whether to purchase and use a BSFL meal product in Nile tilapia production or not is directly influenced by; personal factors, economic factors, institutional characteristics, location, and farm characteristics. Age, gender, marital status, education, and fish farming experience are all considered as personal characteristics in this study. Access to credit and the average income from fish farming are economic characteristics. There are three variables of fish farming characteristics: number of ponds/cages, distance to feed source and knowledge about existing feed components. Access to extension services and membership to fish farmer groups represents institutional characteristics. The location consists of the three counties; Siaya, Kisumu and Homa Bay. The TAM components are modelled to affect awareness and intention to use BSFL meal using structural equation modelling (acceptability). The intervening variables in this study include government regulation, BSFL availability and cultural beliefs. Technical and economically efficient farms improve production output and incur minimum production costs, thus improving household income and food security, as in Figure 2.4.

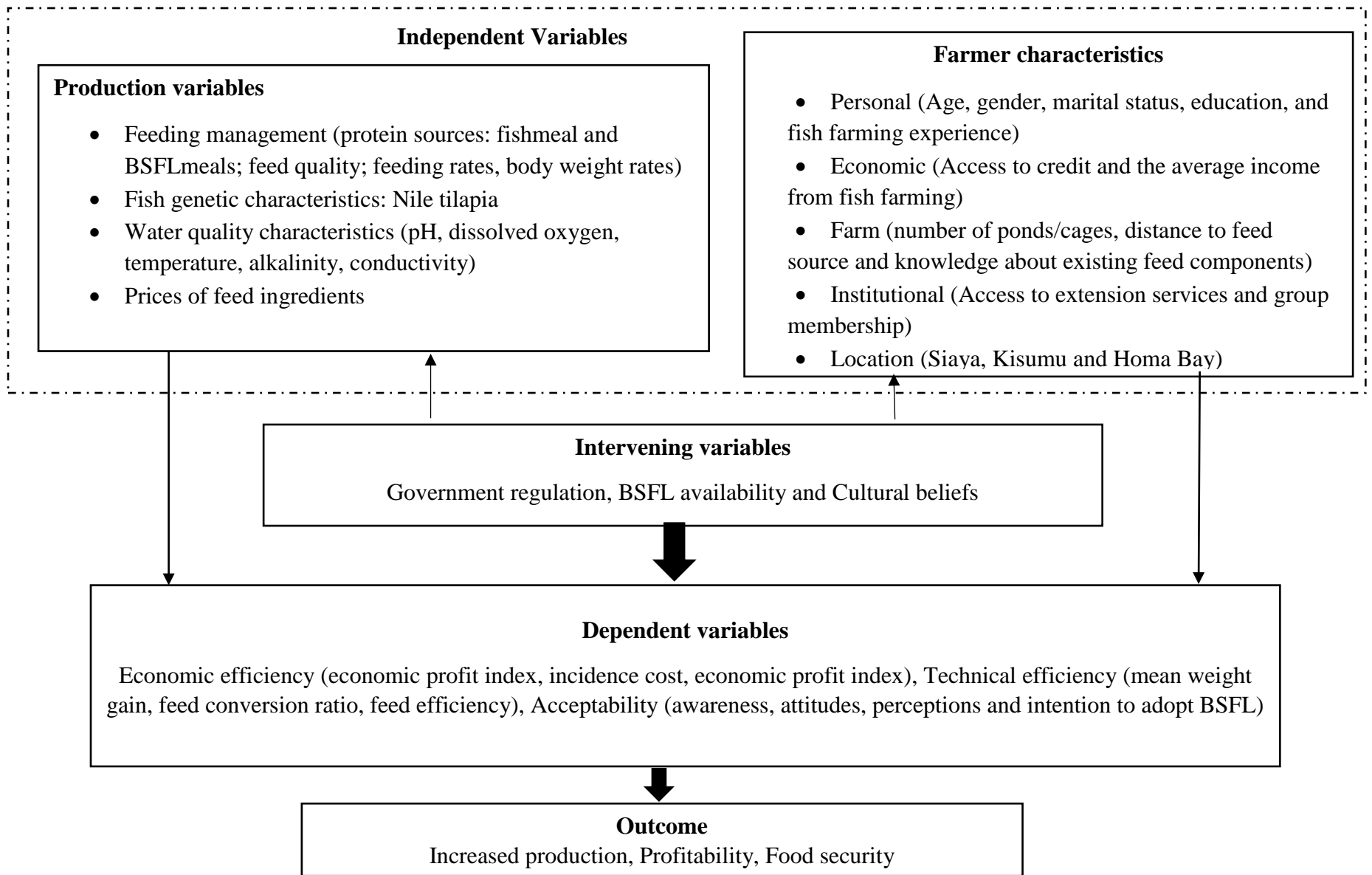


Figure 2.4: Conceptual Framework Reflecting Technical, Economic and Social Efficiency of BSFL meal in Nile tilapia production (Author's conceptualization)

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

This experimental study was undertaken at the Kenya Marine and Fisheries Research Institute (KMFRI), Sangoro Aquaculture Research Station in Kisumu County, Kenya, located at altitude 1134m, latitude $0^{\circ} 21' 13''$ S and longitude $34^{\circ} 45' 26''$ E. Sangoro Aquaculture Research Station is located 70 kilometers from Kisumu City along the Katito-Homabay Road on the riparian floodplain of the River Sondu Miriu in Kenya, which supplies it with water all-year-round. The research institute is stationed on a land characterized by clay soil, which is good for earthen ponds due its high-water retention capacity. There were excellent research facilities within the station for fish research. The trial lasted 26 weeks, from January to June of 2021. Proximate analyses of feed components and formulated feeds were performed at the Kenya Bureau of Standards (KEBS) laboratory in Nairobi, Kenya.

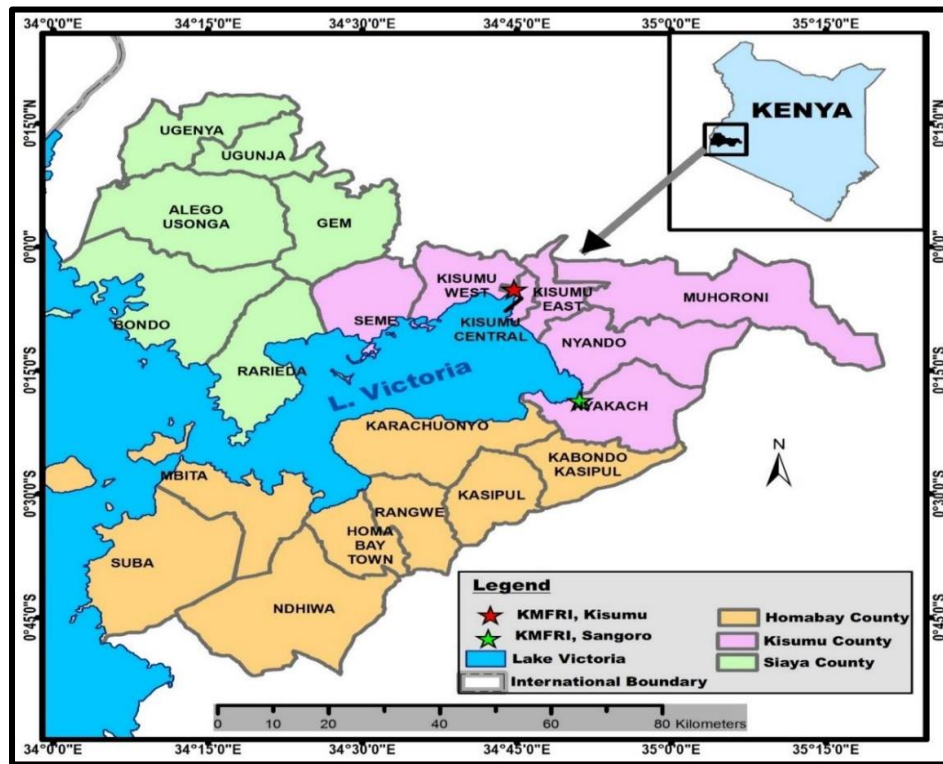


Figure 3.1: Map of the study area

Source: Regional Center for Mapping of Resource for Development [RCMRD] (2020)

The three riparian counties of Siaya, Kisumu, and Homabay in Kenya's Lake Victoria area served as the sites for the survey study (Figure 3.1). With a surface area of 69,000 square kilometers, Lake Victoria is the world's second-largest lake. Tanzania holds 49% of the lake's area, Uganda 45%, and Kenya 6%. According to Opiyo *et al.* (2018), cage farming is presently carried out in five riparian counties: Migori, Siaya, Homabay, Busia, and Kisumu. Highest pond numbers and aquaculture related activities are found in Kisumu County while Siaya and Homabay Counties have the highest number of fish cages (representing 85% and 13% respectively) of the 3,696 fish cages in Lake Victoria, Kenya (Orina *et al.*, 2018). The main species cultured in fish cages is Nile tilapia due to high consumer preference, its fast growth rate, tolerance to crowded conditions and high market value (Ngugi *et al.*, 2007; Munguti *et al.*, 2014; Obiero *et al.*, 2014). Siaya, Kisumu and Homabay counties are some of the counties that have benefited from Aquaculture Business Development Program (ABDP); a venture funded by the Kenyan government and International Fund for Agricultural Development (IFAD), aimed at reducing poverty, increasing food security and improving nutritional status in rural communities hence have high number of aquaculture related activities. Additionally, Siaya county received support from Ministry of Devolution towards Western Kenya Community Driven Development and Flood Mitigation Project, which prioritized cage farming as one of the pathways to poverty alleviation (Ombwa *et al.*, 2018). Table 3.1 summarizes the altitude, rainfall and temperature variations of the three counties where the study was conducted.

Table 3.1: Summary of Altitude, Rainfall and Temperature variations of the study sites

County	Altitude (meters)	Rainfall (mm)	Temperature (°C)
Kisumu	1144-1525 m	1400-1600mm	20.9-35.1
Homabay	1163-1219 m	500-1000mm	17.1-34.8
Siaya	1140-1400m	800-2000mm	16.3-29.1

Source: Author's summaries from literature review (2022)

3.2 Technical and Economic Efficiency of BSFL in Aquaculture

3.2.1 Source of feed ingredients

The ingredients including fishmeal, sunflower cake, soybean meal, maize bran, wheat pollard, cassava flour, binder, vitamin premix, and trace mineral premix were all procured from the fish feed extruder at KMFRI's Sangoro Station. At the same time, sun-dried BSFL were acquired from a farmer in Korowe area, Kisumu County and stored in bags at room temperature until it was used in the experiment. Before proximate analysis, all feed components were crushed into a fine powder (Table 3.2). In this study, the crude protein (CP) of BSFL was 37.03% on a dry matter basis, which was lower than that of fish meal (52.09%). The crude protein content of the BSFL from different substrates generally reflect the nutrient content of the BSFL used. Compared to the 42% reported by Newton *et al.* (2008) and Park (2015), the CP value of the BSFL was lower since the BSFL were reared on different substrates including fruit waste by the farmer from which they were sourced. The BSFL's ash content in this research (14.42%) was within the Makkar *et al.* (2014) report's range of 11 to 28%.

Table 3.2: The Proximate Composition of Fish Feed Ingredient Samples used in the Diet Formation

Sample Number	Moisture (%)	Crude Protein (%)	Crude lipid (%)	Ash (%)	Crude fibre (%)	Carbohydrate %
Fish meal	10.33	52.09	6.78	18.84	1.46	10.5
BSFL	12.38	37.03	8.13	14.42	1.46	-
Soybean meal	8.72	35.38	22.30	4.31	3.64	25.65
Sunflower SC	12.74	16.28	4.90	6.20	9.27	50.61
Maize bran	13.18	10.57	7.27	3.83	5.07	60.08
Wheat pollard	10.94	10.84	5.63	9.31	8.62	54.66
Cassava meal	10.94	13.86	12.90	1.04	1.62	59.64

Source: Field Survey (2021)

3.2.2 Experimental fish and diets

Warm-water fish species in Kenya include African catfish (*Clarias gariepinus*), which accounts for 25% of total fish production, and Nile tilapia (*Oreochromis niloticus*), which accounts for 75%. (Mbugua, 2008; Opiyo *et al.*, 2018). There have been attempts to culture native fish species, including the African carp (*Labeo victorinus*), Victoria tilapia (*Oreochromis variabilis*), and indigenous tilapiine species like *Oreochromis esculentus* (Maithya *et al.*, 2017; Orina *et al.*, 2018). However, because of their low survival and production rates, farmers have not widely adopted their cultivation, which has remained experimental (Orina *et al.*, 2018). Nile tilapia (*Oreochromis niloticus*) is the subject of this study since it is an important species in aquaculture on a global scale because of its fast growth, firm and tasty flesh, resistance to harsh settings, and ease of raising fingerlings in captivity (Githukia *et al.*, 2015).

About 1200 sex-reversed *Oreochromis niloticus* fry were procured from Apondo Fish Farm in Ahero, Kisumu County, and acclimatized for two weeks before being fed on the control diet. Following acclimation, the fingerlings were randomly selected and put into twelve hapa nets of size 2 m × 2 m × 1 m (4 m³) anchored in an earthen pond of size 15 × 20 (300 m²). Within the earthen pond, a 1 m space was maintained between the hapa nets. Throughout the experiment, the fish were hand-fed twice daily at 10 am and 4 pm by dispersing feed at 5% of body weight at the periphery of each hapa net and feeding rates were adjusted based on the body weight. The fish were stocked in the hapa nets at a rate of 100 fingerlings per unit area of hapa net. The hapa nets were cleaned monthly during sampling period to prevent clogging and enhance good circulation of fresh water.



Figure 3.2: Experimental set-up at KMFRI Sangoro Station, where feeding trials were done from January to June 2021

This study used an experimental design with a Completely Randomized Design (CRD) comprising of four treatments triplicated. CRD was preferred since the experimental material were homogeneous and there were few numbers of treatments (4) hence small number of degrees of freedom. Four identically nutrient- and calorie-rich diets were formulated. BSFL was used to substitute FM derived from silver cyprinid (*Rastrineobola argentea*) at 0% (control diet-T1), 25% (Diet T2), 50% (Diet T3), and 75% (Diet T4) as the protein ingredient. FM was the main protein source in the control diet. The diets were formulated to meet the optimal feeding standards of Nile tilapia fish. This study used full-fat BSFL. According to Caimi et al., (2020), defatting may reduce the nutritional and functional value of insect meals due to the possibility of amino acid and antimicrobial protein degradation at high temperatures and an increase in the meal's chitin content, which in excess may be considered an antinutritional factor that reduces nutrient digestibility. Moreover, by separating the fat, the favorable components of the fatty acid composition, such as the high levels of lauric acid content, are reduced in insect diets (Wang *et al.*, 2019). Additionally, due to the significant energy consumption, labor costs, and additional

expenses involved in the processes of fat extraction and protein purification, the use of insect meals can be less profitable and less environmentally sustainable (Liland et al., 2017)

3.2.3 Analytical methods

At the beginning of the experiment, standard protocols were used to test the individual dietary elements' including crude protein, moisture, crude fibre, fat and ash contents (Association of Official Analytical Chemists [AOAC] 1984). The ingredients component quantities of the experimental diets are shown in Table 3.3. The ingredients for the test diets were blended and ground to a uniform size.

Table 3.3: Formulation (% dry weight) and proximate composition (% DM) of experimental diets.

Parameter	Control	BSFL25	BSFL50	BSFL75
BSFL	0	12.28	24.57	36.86
Fish Meal	35	26.25	17.5	8.5
Soybean Meal	34	34	34	34
Sunflower cake	2.6	2.6	2.6	2.6
Maize bran	6	6	6	6
Wheat Pollard	3	3	3	3
Cassava Flour	7	7	7	7
Binder	0.2	0.2	0.2	0.2
Vitamin premix	0.1	0.1	0.1	0.1
Trace mineral premix	0.1	0.1	0.1	0.1

Source: Field Survey (2021)

3.2.4 Water quality measurements

Water parameters, including dissolved oxygen (mgL^{-1}), pH, and temperature ($^{\circ}\text{C}$) were measured in situ by dipping a probe into the water surface on a weekly basis using a multiparameter water quality meter, model H19828 (Hanna Instruments Ltd., Chicago, IL, USA) (About 20-25 cm). There was no aeration provided, however water was regularly pumped into the pond to replace evaporation and seepage losses.

3.2.5 Sampling and determination of growth parameters

After every 14 days, 30 representative fish from each experimental hapa net were randomly sampled. Wet body weight (g) and length (cm) were measured using a fish measuring board to

the nearest 0.01cm and a digital weighing scale (Mettler Toledo-AG204, Japan) with a reading of 0.01 g to track growth performance and mortalities. The fish were promptly released to their respective hapa nets following weight and length measurements. Additionally, the daily feed intake was noted. Fresh feeding rates were determined after each sampling and modified depending on the average fish weight. At the conclusion of the experiment, the fish were collected, weighed, and counted. Several growth and nutrient utilization measures, including weight gain, specific growth rate (SGR), survival rate, feed conversion ratio (FCR), feed efficiency (FE), and condition factor, were used to evaluate the effects of diet on fish growth performance (K). The following formulas were used.

$$\text{Mean Weight Gain (MWG)} = \text{Final mean weight (W1)} - \text{initial mean weight (W0)} \quad (3.1)$$

$$\text{Specific Growth Rate (SGR)} = \frac{(\text{final mean weight}) - \ln(\text{initial mean weight})}{\text{time in days}} \times 100 \quad (3.2)$$

$$\text{Survival rate (\%)} = \frac{\text{Number of fish at the end of the experiment}}{\text{Number of fish at the beginning of experiment}} \times 100 \quad (3.3)$$

$$\text{Feed Conversion Ratio (FCR)} = \frac{\text{Average feed intake (g)}}{\text{Mean weight gain (g)}} \quad (3.4)$$

$$\text{Feed efficiency (F.E.)} = \frac{\text{Live weight gain by fish (g)}}{\text{Total feed fed (g)}} \quad (3.5)$$

$$\text{Condition factor (K)} = \frac{W}{L^b}; \quad (3.6)$$

Where W = the total weight of fish (g) and L = the total fish length (cm).

Measuring FE in aquaculture entails measuring feed intake (De Verdal *et al.*, 2018). Reducing feed consumption per kilogram of fish produced or increasing fish production from the same amount of feed are two ways to increase FE, reflecting the diet's technical efficiency. Therefore, enhancing feed efficiency is essential for reducing production costs.

3.2.6 Economic Analysis Indicators

The study performed an economic analysis to determine the economic efficiency of using BSFL as a fishmeal alternative. The economic study was done to determine the cost of feed necessary to raise a kilogram of BSFL-fed fish cultured under controlled conditions. The economic

analyses were conducted using the Economic Conversion Ratio (ECR), Economic Profit Index (EPI), and Incidence Cost (IC) following the procedure of El-Saidy & Gaber (2003).

ECR measures feed economic efficiency by multiplying FCR and the cost of feeds while EPI measures the economic efficiency of a feed by considering the weight gain of fish, selling price and cost of feeds (Musita *et al.*, 2016). The higher the EPI, the more economically efficient or profitable the feed. FCR was computed using the formula in equation 3.4 based on fish's feed intake and weight gain during the feeding trial. The ECR and EPI were calculated as in equation 3.7 and 3.8:

$$ECR \text{ (Kshs per Kg of fish)} = CF \times FCR \quad (3.7)$$

$$EPI \text{ (Ksh per fish)} = (WG \times SP) - (WG \times CF) \quad (3.8)$$

Where *FCR* is feed conversion ratio (kg feed per kg fish); *CF* is the cost per kg feed; *WG* is weight gain in kg; *SP* is selling price in KSh per kg of fish. Feed costs were determined using ingredient prices and the quantities of each item used in the dietary treatment. The study computed the feed cost necessary to make 1 kg of feed, considering that the feed cost is dependent on the BSFL meal composition. All other production costs, except the cost of the feed, were considered to be constant for all dietary treatments. According to market values at the time of the experiment, the price of each experimental feed was determined by the cost of the ingredients employed in its formulation. The cost of the ingredients used in the formulation of each experimental diet at the time of the experiment was determined by market values at the period of the experiment, with dried BSFL costing an average of 0.80 US Dollar (USD) (Mutisya *et al.*, 2021). Table 3.4 lists the price per kilogram, in KSh, of each component bought from a commercial merchant, excluding labour and taxes. This resulted in a per kg feed cost of T1= Ksh 91.402, T2=Ksh 87.314, T3=Ksh 83.233, T4=Ksh 78.755. Nile tilapia sales price was calculated at Ksh per kg. Vitamin and mineral premix were added at 1% of the formulated feed. Fish from each pond were pooled for each dietary treatment and priced at 300 Ksh per kg, the market price for 1 kg body weight of fresh unprocessed Nile tilapia (Musa *et al.*, 2021).

The incidence cost, or relative cost per unit weight increase, is the feed cost needed to produce one kilogram of fish; the lower the feed cost, the more profitable the feed is (Nwanna, 2003). Equation 3.9 was used to compute the incidence cost.

$$\text{Incidence Cost}(I.C.) = \frac{\text{Cost of feed}}{\text{Weight of fish produced}} \quad (3.9)$$

Table 3.4: Price of Feed Components (KSh) Utilized in Formulating Meals Containing BSFL as a Substitute for Fishmeal

Ingredients	Market price in KSh/kg
BSFL	80
Fishmeal	159
Soybean meal	85
Sunflower	32
Maize bran	34
Wheat pollard	34
Cassava	30
Vitamin premix	360
Trace Mineral	500

1 USD= 100 KSh (Prices conversion are based on the market price of ingredients as of January 2021)

Source: Field Survey (2021)

3.2.7 Data analysis

Firstly, the normal distribution of the data was verified using Kolmogorov–Smirnov test and the Shapiro-Wilk test. To confirm the homogeneity of variance on data sets, it was subjected to the Levene test. The experimental tanks were arranged in a Completely Randomized Design (CRD) and treatment diets replicated; therefore, the experimental design fulfilled the third assumption of using ANOVA, which demands that observations be independent of each other. Data were then subjected to a one-way analysis of variance (ANOVA) followed by Tukey's post hoc test. Pearson's correlation was utilized to evaluate the relationship between the measured parameters. The optimal substitution level of BSFL meal was established using a broken line model and mean fish weight.

All analysis was performed using Statistical analyses were performed using SPSS Version 25. Probabilities of $p < 0.05$ were defined as significant. Significant different means among various treatments were evaluated using the Tukey– Kramer post hoc test. Results are reported as the “mean \pm S.E.” (S. E referring to the standard error of the mean). General linear model for completely randomized design (CRD) was as in equation 3.10

$$Y_{ij} = \mu + T_i + \varepsilon_{ij} \quad (3.10)$$

Where Y_{ij} = Total observation on j^{th} and i^{th} treatment

μ = overall population means

T_i = the effect due fishmeal- black soldier fly soldier larvae meal mixture level (0, 25, 50 and 75%)

ε_{ij} = is the error term

3.3 Awareness, Attitudes, Perceptions, and Intention to Use BSFL in Aquaculture

3.3.1 Sampling Procedure and Sample Size

A cross-sectional survey approach was used in this study to gather first-hand information about fish farmers' awareness and intent to utilize BSFL. The respondents were chosen using a multi-stage sampling approach. All active fish ponds and cage farmers engaged in Nile tilapia cultivation in the study region were designated as the sample frame for this study. Table 3.5 shows the distribution of households rearing fish in the three counties of study (Homabay, Kisumu and Siaya).

Table 3.5: Distribution of households rearing fish by county

County	Fish ponds	Fish cages	Total
Homabay	939	174	1,113
Kisumu	698	138	836
Siaya	564	311	875
Total	2,231	623	2,854

Source: KNBS (2022)

The sample size for this study was 227 respondents; this was obtained using Raosoft Online sample size calculator. Raosoft sample size calculator uses a given margin error (confidence interval) =5% (usually a common choice), and a confidence level =95% (other typical choices are 90% or 99%), response distribution = 80%, while the population size = 2,854 (total households rearing fish in the three counties as in table 3.5). However, from a list of farmers supplied by the Sub-County Fisheries Officers in each of the three chosen counties, Kisumu, Siaya, and Homabay, Kenya, a total of 211 fish farmers were selected through a census based their present active uptake of aquaculture as shown in Table 3.6.

Table 3.6: Distribution of respondents by farmer category per county

Farmer Category	County			Total
	Siaya	Kisumu	Homabay	
Fish pond farmer	45	33	35	113
Cage farmer	35	34	29	98
Total	80	67	64	211

Source: Field Survey (2021)

3.3.2 Data Collection

A structured questionnaire was designed according to the TAM and included other socio-demographic variables. Trained enumerators conducted the face-to-face survey between December 2020 and April 2021. The survey tool comprised two main sections; the first contains questions on farm and farmer characteristics. Feeding procedures, feed prices, feed kinds and sources utilized on the farm, and other issues linked to fish farming were also obtained. In the second section, participants were assessed for their knowledge of insect-based feeds, including BSFL, and their level of agreement with a set of statements (constructs derived from literature review) using a five-point Likert scale, with 1 being the strongest disagreement and 5 being the strongest agreement. The statements were made to demonstrate their BSFL objectives, outlook, perceived usefulness, and perceived ease of use (Table 3.7). The research components were built entirely on previously validated measurements. All scale items were rearticulated to correspond closely to the requirements of the current investigation. According to Nunnally (1978), a minimum of three items were utilized for each construct to provide enough reliability. The statements function as markers for estimating the latent variables.

Table 3.7: Latent variables, indicator ID, and the corresponding questionnaire statements used within the survey

Indicator	Item Measure	References
Perceived Usefulness		
PU1	Improve the sustainability of fish production	Chia <i>et al.</i> , 2019
PU2	Improve the societal acceptance of fish farming	Verbeke <i>et al.</i> , 2015
PU3	Lower the ecological footprint of livestock farming	Chaalala <i>et al.</i> , 2018
PU4	Allow farmers to produce high quantities of fish for the world population	Verbeke <i>et al.</i> , 2015
PU5	Lower production costs in fish farming without fish reducing quality	Sinansari & Fahmi, 2020
PU6	Decrease the overexploitation of water bodies	Tiu, 2012
PU7	Lower our dependence on foreign protein sources	Verbeke <i>et al.</i> , 2015
PU8	Lower the cost of Fish feed	Verbeke <i>et al.</i> , 2015
PU9	Lower our reliance on imported feed	Verbeke <i>et al.</i> , 2015
PU10	Improve organic waste management in the country	Dicke, 2018
Perceived Ease of Use		
PEOU1	Use of BSFL feed is a system easy to understand	Oppong, 2017
PEOU2	Use of BSFL is a system that would be easy to implement on my fish farm.	Rana <i>et al.</i> , 2015
PEOU3	Using BSFL meal would enhance my effectiveness in fish production	Mulumpwa, 2018
PEOU4	Using BSF meal will improve my fish production efficiency	Roffeis <i>et al.</i> , 2018
Attitude towards Use		
ATT1	BSFL provide a cheap source of protein in fish farming	Higa <i>et al.</i> , 2020
ATT2	BSFL Provide nutrients and minerals	Makkar <i>et al.</i> , 2014
ATT3	Possibility of rearing BSF guarantees availability	Yildirim-Aksoy <i>et al.</i> , 2020)
ATT4	Rearing BSF requires small space and is cost-effective	van Huis, 2013
ATT5	BSF has low feeding costs because it feeds on wastes, thus cleaning the environment	Dicke, 2018
ATT6	Hard to create awareness and promote BSFL meals to people based on legislative issues	Belghit <i>et al.</i> , 2019
ATT7	Long time is required to change people's attitudes to consider BSFL meals as feed.	Kelemu <i>et al.</i> , 2015
Intention to Use		
INT1	I intend to use BSFL in my fish farm	Ssepunya <i>et al.</i> , 2019
INT2	I would recommend the adoption of BSFL meals for other fish farmers in my region.	Domingues <i>et al.</i> , 2020
INT3	I would also adopt BSFL meal if the neighboring farmers adopt	Joffre <i>et al.</i> , 2020

Source: Field Survey (2021)

The questionnaire was pretested to avoid potential issues with time management, complexity, suitability, and appropriateness during use. The pre-feedback tests were utilized to improve the questionnaire. The finished survey was uploaded to the Kobo Collect platform, which was used to gather data via mobile devices.

3.3.3 Empirical Framework for Farmer's Awareness

The linear regression model faces many fundamental problems when the dependent variable is binary, including non-normality of the error term, heteroscedasticity of the error term, the possibility of a result outside the 0-1 range, and a typically low coefficient of determination (Gujarati, 2003). It is guaranteed by the logit and probit models that the expected value will range from 0 to 1. The impact of various variables on BSFL awareness was examined using the binary logit regression model. The logit regression model was chosen because substantial research has shown that it can be applied to study farmer's awareness (Muatha *et al.*, 2017; Mustafa *et al.*, 2019; Obi-Egbedi *et al.*, 2020; Ullah *et al.*, 2022). The probit model does not perform better in practical research than the logistic distribution due to the computational difficulties caused by the lack of a closed form for the normal cumulative density function, which the probit model is based on (Ai & Norton, 2003). The dependent variable for this study was the farmers' awareness or unawareness of BSFL with a value of 1 (if the farmer is aware of BSFL) and 0 (if the farmer is not aware of BSFL). Table 3.8 displays the independent variables and their values. The independent factors predict the response variable (awareness of BSFL).

Odds ($Y=1$), or the ratio of the chance that $Y=1$ to the probability that $Y \neq 1$, predicts the likelihood that the farmer is aware of BSFL;

$$Odd Y = P(Y = 1)/(1 - P(Y = 1)) \quad (3.11)$$

The binary logit regression model is specified as follows.

The natural log of odds yields the logit (Y);

$$\ln \left\{ \frac{p(Y_i=1)}{1-p(Y_i=1)} \right\} = \log Odds = Logit (Y) \quad (3.12)$$

This can be expanded as in equation 3.13

$$Logit(Y) = \alpha + \sum \beta_1 X_1 + \sum \beta_2 X_2 + \dots + \sum \beta_n X_n + \epsilon_i \quad (3.13)$$

Where Y = dependent variable (awareness) with 1= aware and 0= otherwise;

α = intercept

ε_i = error term

β_1, \dots, β_n = coefficients of the independent variables

X_1, \dots, X_n = the independent variables (Table 3.7)

$p(Y_i = 1)$ = probability of being aware of BSFL

$1 - p(Y_i = 1)$ = probability that a farmer is not aware of BSFL

and \ln = natural log

To evaluate the immediate impact of changes in the explanatory factors on the projected chance of being aware while maintaining other explanatory variables constant, marginal effects were computed.

Table 3.8: Description of variables used in the binary logit regression model

Variables	Type	Description	Value
Dependent Variable			
Awareness of BSFL (Y)	Dummy	Farmer is aware or unaware of BSFL	1 if aware, 0 if unaware
Independent Variables			
Age (X ₁)	Continuous	Age of the respondent	Years
Gender (X ₂)	Dummy	Gender of the respondent	1 if Male, 0 if Female
Education (X ₃)	Categorical	Highest level of education of the respondent	1 if Primary level, 0, Otherwise
Extension Access (X ₄)	Dummy	Whether the respondents have participated in training related to BSFL	1 if attended 0 if not attended
Number of ponds/Cages (X ₅)	Continuous	Total number of cages and ponds owned by the respondent	Number
Farming experience (X ₆)	Continuous	Total fish farming experience of the respondent	Years
Group Membership (X ₇)	Dummy	Membership in a fish farming group	1 if a member 0, otherwise
Credit Access (X ₈)	Dummy	Access to credit for fish farming activities	1 if
County(X ₉)	Categorical	County of fish farming by the respondents	1 if Siaya, 0 otherwise
Distance to Feed Source(X ₁₀)	Continuous	Distance to input market (feed source)	Kilometers
Knowledge about Existing Feed (X ₁₁)		Knowledge about the components of the existing feed	1 if aware, 0 otherwise
Average Income(X ₁₂)	Continuous	Average Income from fish farming	KShs
Marital status (X ₁₃)	Categorical	Marital status of the fish farmers	1 if Married, 0 otherwise

Source: Field Survey (2021)

3.3.4 Test for Multicollinearity

A multicollinearity test was performed using a variance inflation factor (VIF) computation to ensure that the model's explanatory variables were not connected. A simple ordinary least squares (OLS) regression was computed with the dependent variable and the remaining explanatory factors. The VIF assesses the severity of multicollinearity in an ordinary least

squares regression. According to Gujarati (2004), VIF demonstrates how the presence of multicollinearity increases the variance of an estimate. The below equation 3.14 was used to calculate VIF:

$$VIF = \frac{1}{1-R_i^2} \quad (3.14)$$

Where R_i^2 is the R^2 of the regression with the i^{th} independent variable as a dependent variable.

Table 3.9 presents the results of the VIF.

Table 3.9: Variance Inflation Factor Results

Variable	VIF	1/VIF
logAverageIncome	2.13	0.4693
Group Membership	2.05	0.4874
Distance to Feed Source	1.93	0.5183
Credit Access	1.88	0.5318
Age	1.51	0.6602
Knowledge of Existing Feed	1.46	0.6867
County	1.37	0.7273
Marital Status	1.36	0.7368
Gender	1.32	0.7574
Extension Access	1.24	0.8069
Number of Ponds/Cages Owned	1.2	0.8353
Education level	1.18	0.8492
Farming Experience	1.16	0.8641
Mean VIF	1.52	

Source: Field Survey (2021)

Explanatory factors' VIFs range from 2.13 to 1.16, and the mean VIF is 1.52. The independent variables' VIF is less than five. None of the independent variables was found to have a significant correlation, suggesting no multicollinearity problem.

3.3.5 Analytical Framework

The degree to which the variables in the conceptual model are interdependent was evaluated using the Partial Least Squares Structural Equation Modeling (PLS-SEM) method. Since TAM constructs are latent, they cannot be seen or quantified directly. Consequently, a set of

measurements that act as indicators for the underlying latent variable were created utilizing a series of questions. Thus, the outer sub-model of the structural equation model represents the relationships between the latent variables and their observable indicators. The relationship between the dependent and independent latent variables and their related path coefficients are then evaluated by introducing an inner sub-model (Wong, 2013). In structural equation modelling (SEM), factor analysis and multiple regression analysis are employed (Chin, 1998). By concurrently calculating cause-and-effect linkages between several dependent and independent latent variables, SEM may assess theoretical connections. Covariance-based SEM (CB-SEM) and partial least squares SEM (PLS-SEM) are the two methods of SEM (Haenlein & Kaplan, 2004).

Partial Least Squares SEM (PLS-SEM) was chosen to test the hypotheses in this study in accordance with the guidelines for selecting a SEM method (Hair *et al.*, 2017) for two reasons: (1) the research objective is an exploratory theory based on the total variance in the area of agricultural technology adoption, and the goal of this analysis is prediction; and (2) the research objective is to use latent variable scores in subsequent analyses (Ringle *et al.*, 2014). Due to the non-normal data and limited sample size, PLS-SEM was a suitable option for our data analysis since it is more acceptable for non-normal data and small sample sizes than covariance-based SEM (Hair *et al.*, 2014). PLS-SEM needs to be assessed in two processes. The first stage assesses the link between the indicators and the latent variable outer model (measurement model). The causal association between the latent variables is calculated in the second stage (inner model; structural model). The structural model and hypothesis were examined using Smart PLS 3.0. The statistical significance of the standardized path coefficients was confirmed using t-statistics, which were obtained using a bootstrapping method with 5,000 sub-samples (β).

3.4 Stakeholders' Perspectives on the Use of BSFL in Aquaculture in Kenya

3.4.1 Study design and sampling

Cross-sectional online survey was conducted to examine stakeholders' opinions on using BSFL in aquaculture. Potential participants were selected by reviewing academic articles and their participation in scientific conferences by utilizing broad keywords in online search engines and

through professional networks. The sampling strategy identified experts undertaking studies on Black Soldier Fly (BSF) as a feed. The panel sought experts in several relevant sectors and disciplines to guarantee breadth of perspectives. Further, data were gathered using the snowballing approach. As employed by Habibi *et al.* (2014), the researcher initially identified a few experts, and after obtaining the information, additional experts were found. The 40 participants who were targeted were from government agencies, academic institutions, and industry.

3.4.2 Data Collection

After looking at pertinent published and unpublished research, having casual conversations with specialists, and researching the present state of the use of insects as aquaculture feeds, the survey questionnaire was created. A Google Drive-created saved and shared anonymous online questionnaire was used to gather responses from stakeholders. It was challenging to gather all participants in one location at the same time to discuss and come to a consensus on the aspect of BSFL sustainability in aquaculture since they came from different professions and geographical locations, as well as due to the COVID-19 pandemic. Further, due to time, money, and geographic restrictions, this study employed an online Delphi survey to investigate its objectives. The 1950s saw the creation of the Delphi technique, which is currently frequently utilized to gather information from qualified professionals (Rowe & Wright, 2011). According to earlier research (Imang & Ngah, 2012), the Delphi method is an effective research technique for (i) deriving consensus among experts from various geographic locations on a particular issue and (ii) deriving consensus among experts on a challenging issue when access to information is limited (Hauck *et al.*, 2007). To reach an agreement, several aquaculture researchers have used the Delphi method (Soon & Baines, 2012; Valderrama *et al.*, 2014; Marvin *et al.*, 2020; Weitzman *et al.*, 2021). Experience from prior Delphi research demonstrates that even with small sample numbers, this approach is practical for expert judgements. The 24 experts who responded were a sufficient representative sample out of the 40 experts who were invited to participate in the survey (Mukherjee *et al.*, 2018).

The online survey was utilized to speed up the process and save participants' time, which increased the questionnaire's effectiveness. Using a web-based survey platform and a questionnaire made statistical analysis simpler, removed the need for paper surveys, and reduced data entry and computer errors. It took about 20 to 30 minutes to complete the questionnaire. The survey was closed to new responses after six weeks. There were open-ended and closed-ended questions in the questionnaires. A questionnaire draft was pretested to evaluate the questions' readability, length, and usability of the online system. After the pilot, the questionnaire's number of questions, tone, and subject matter were revised. In the consent section of the invitation to participate in the study, potential participants were informed about the purpose of the study, what it included, and that they would not be identified by name in any subsequent publications.

3.4.3 Data Analysis

A 5-point Likert scale was used to solicit responses about the perceived benefits and risks of using BSFL in aquaculture ranging from (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree. Additionally, experts were asked to rank 11 indicator criteria on a scale of 1 to 5, where 1 represents least important, and 5 represents extremely important. The degree of agreement between the expert-ranked rating scores of the indicator variables was evaluated using the Kendall Coefficient of Concordance (Legendre, 2010). Equation 3.15 was used to construct Kendall's Coefficient of Concordance, which measures how much the ranks agree or differ. W has a positive value and ranges from zero (which denotes the greatest degree of disagreement) to one (which means there is a perfect agreement).

$$W = \frac{12[\sum T^2 - (\sum T)^2/n]}{nm^2(n^2-1)} \quad (3.15)$$

Where m is the number of experts sampled, n is the number of items ranked, and T is the sum of the rankings for each item. The consistency and reliability of the results based on the Likert scale estimate were also assessed using Cronbach's alpha. Each expert's data was saved in a database on a web server. Data were exported to Excel at the end of the survey, where basic data processing and quality checks were carried out.

To analyze qualitative data, software Nvivo v. 12 software was used. Audio and video recordings of the focus groups were transcribed and coded using a thematic analysis that is particularly effective to identify and describe themes within a dataset and find patterns among the sample. The qualitative approach used for the analysis incorporated both inductive and deductive methodologies. For this purpose, at first, data were organized in common themes and sub-themes by coding. Themes were generated based on the research questions and recorded under five different nodes. Inductive codes were generated by looking at data and by identifying possible recurring topics. Participants' quotations belonging to the same themes were codified and recorded under the same node. Each node was successively ramified in sub-nodes, allowing a better distribution and classification of themes and sub-themes. The validity of themes and codes was double-checked. The literature review was used deductively to answer the research question at hand.

3.5 Ethical consideration

The study sought clearance from Jaramogi Oginga Odinga University of Science and Technology's Board of Post-Graduate Studies (JOOUST). The JOOUST Ethical Review Committee evaluated and approved all methods involving the use of insects and fish subjects. Permission to conduct research was obtained from JOOUST's Board of Postgraduate Studies and the National Commission for Science, Technology and Innovation (NACOSTI). Furthermore, the questionnaire included an introduction statement that requested the respondent's consent to participate in the study.

CHAPTER FOUR: TECHNICAL AND ECONOMIC EFFICIENCY OF BLACK SOLDIER FLY LARVAE IN AQUACULTURE PRODUCTION

4.1 Technical Efficiency of BSFL in Aquaculture Production

4.1.1 Water quality parameters

Table 4.1 summarizes the parameters relating to water quality. The physicochemical characteristics of water quality are critical for optimal fish development. Fish are sensitive to a wide range of water quality. Feeding should be restricted or halted if water quality falls below specific thresholds. All water quality metrics were within the tolerable limits for earthen pond tilapia culture (Popma & Mass, 1999; EL-Sayed, 2006; Mjoun *et al.*, 2010; Bhatnagar & Devi, 2013). Ani *et al.* (2020) found that the dissolved oxygen range between 4-6 mg/L is appropriate for a fish culture unit. The pond's reported ideal water quality ranges may be due to efficient pond management practices such as delivering the right amount of feed based on the recommended feeding rate to prevent feed waste. The water level maintenance in the pond also replenished the pond with freshwater through constant top-up.

Table 4.1: Water Quality Parameters

Parameter	Mean
Alkalinity	184.06 ±10.81
Conductivity	466.78 ± 11.32
Dissolved Oxygen (D.O)	6.65 ± 0.13
Potential Hydrogen (pH)	7.33 ± 0.05
Temperatures	24.78 ± 0.64

Source: Field Survey (2021)

4.1.2 Technical Efficiency Indicators

Results for the growth performance parameters are compiled in Table 4.2. At the end of the trial period, the mean body weight varied from 20.4 to 23.24 g, up from an initial mean body weight range of 0.10-0.41 g. Regarding final body weight, weight gain, daily weight gain, survival rate, SGR, FCR, FE, and condition factor, T3 was superior to all tested diets, followed by T1, T4, and T2. T4 had the highest final mean length and length gain, followed by T1, T2, and T3. However,

no significant difference was recorded in all growth parameters ($P > 0.05$). All the growth parameters were lower in the diet T2 except for final mean length and length gain. Currently the aquaculture industry has placed a lot of focus on the feeding strategies that can achieve optimum Nile tilapia growth, which has high demand because of its popularity as a cheap and nutritious animal protein source (Dawood *et al.*, 2020). Other researchers have reported BSFL meal as a potential protein source in fish feeds that can replace fishmeal (Abdel-Tawwab *et al.*, 2020; Yildirim-Aksoy *et al.*, 2020; Hu *et al.*, 2020; Weththasinghe *et al.*, 2021; Tippayadara *et al.*, 2021). The current study results show that fish fed on 50% BSFL meal had improved performance indicators of tilapia, which were not significant from the other treatments including T1. The survival rates were also not significantly different across the four treatments, indicating that the BSFL had no adverse effect on fish survival. Most of the mortalities were observed a day after sampling, which could be due to stress posed during length-weight measurements. This suggests that the formulated diets provided close to similar nutrients to the fish. Higher than 50% BSFL inclusion level reduced fish growth performance due to reduced palatability. According to Kroeckel *et al.* (2012), fish diets that substitute an alternative source of protein for fishmeal exhibit decreased palatability, mainly when the replacement diets contain anti-nutritional elements. Due to the presence of anti-nutritional elements, other additives such as soybean meal utilized in feed formulation have been observed to gradually reduce fish performance (Obirikorang *et al.*, 2015).

Based on these findings, Rana *et al.* (2015) also concluded that mono-sex tilapia given 50% BSFL meal replacement with fishmeal (FM) did not exhibit any difference in growth characteristics from the control. Ushakova *et al.* (2018) also observed a substantial increase in daily weight gain on tilapia fed for 30 days with dried flour of BSFL meal pre-pupae at a dose of 0.5 gKg^{-1} , with no significant differences in survival rates. The outcomes also support those of Dietz and Liebert (2018), who claimed that using 50% BSFL meal as a replacement for soy protein concentrate had no appreciable impact on Nile tilapia's ability to grow. There were no negative impacts on growth performance even when BSFL meal inclusion levels were reduced to 50% to replace FM (Muin *et al.*, 2017). Similar to this, Devic *et al.* (2017) observed that feeding tilapia 80g of BSFL per kilogram of food had no negative impacts on growth performance.

While Fisher *et al.* (2020) found that Atlantic salmon fed on a diet containing 200 gkg⁻¹ of BSFL meal recorded the same growth performance as the control. Toriz-Roldan *et al.* (2019) found that BSFL inclusion at a rate of 6% did not alter growth performance. Similarly, Abdel-Tawwab *et al.* (2020) found no changes in growth or survival in a culture of European sea bass (*Dicentrarchus labrax*) fed on a 50% BSFL inclusion level.

Data on feed conversion ratio (FCR) from research on Nile tilapia appear to be influenced by growth phases, feed type, and culture method. The FCR for diet T3 was the lowest (0.47 ± 0.02), while the FCR for diet T2 was the highest (0.54 ± 0.04). The lower FCR in T3 suggests improved feed use for metabolic and tissue-synthesis processes. There were no significant differences between the treatments fed on different amounts of BSFL; however, the assessed nutrient utilization indices, such as FCR and FE, were greater in T3. Diet T3 had the greatest FE (213.21 ± 10.59), while diet T2 had the lowest FE (187.40 ± 13.70). The input-output ratio provided by the FE and FCR gauges technical efficiency (TE). The TE of a diet increases as FE increases. A lower FCR indicates higher utilization of the fish feed and is a vital measure of the quality of fish feed. T3 was the diet that was technically the most efficient. Nutrients are used similarly across diets suggests that BSFL meal can take the role of FM. These outcomes were consistent with those seen in the culture of tilapia (Tippayadara *et al.*, 2021), rainbow trout (*Oncorhynchus mykiss*) (Renna *et al.*, 2017; Dumas *et al.*, 2018), Atlantic salmon (*Salmo salar*) (Belghit *et al.*, 2019; Fisher *et al.*, 2020; Li *et al.*, 2020), Japanese seabass (*Lateolabrax japonicas*) (Wang *et al.*, 2019), Zebrafish (*Danio rerio*) (Zarantoniello *et al.*, 2019), and European sea bass (*D. labrax*) (Magalhães *et al.*, 2017; Abdel-Tawwab *et al.*, 2020).

The lack of significant differences in growth and nutrient utilization indices could be explained by high crude fibre in insects because of the insect's exoskeleton that has content of chitin, a complex carbohydrate that Nile tilapia fry may have trouble digesting (Fontes *et al.*, 2019) resulting to slow growth rates, especially with higher than 50% BSFL inclusion level. The quality of CP is also an essential factor that can affect feed utilization. Even though all the diets were isonitrogenous, decreasing fish meal and increasing the BSFL meal can reduce the quality of dietary protein. Even though the amino acid profile of the components in this study was not known, Mjoun *et al.* (2010) emphasized that the quality of protein in fish diets is a function of the proper amount of essential amino acids.

Table 4.2: Summary of the Growth Performance Parameters

Growth Parameters	Diets				P-value
	T1	T2	T3	T4	
Initial weight (g)	0.10 ± 0.01	0.12 ± 0.01	0.15 ± 0.01	0.41 ± 0.28	0.367
Initial length (cm)	3.12 ± 0.08	3.26 ± 0.08	3.48 ± 0.08	3.28 ± 0.08	0.246
Final Mean Weight (g)	21.75 ± 0.64	20.41 ± 1.49	23.24 ± 1.15	21.60 ± 0.40	0.339
Final length (cm)	11.45 ± 0.32	10.85 ± 0.32	10.66 ± 0.32	11.80 ± 0.32	0.113
Weight gain (g)	21.65 ± 0.64	20.30 ± 1.48	23.09 ± 1.15	21.19 ± 0.12	0.316
Length gain (cm)	8.33 ± 0.26	7.59 ± 0.05	7.18 ± 0.30	8.52 ± 0.64	0.114
Survival (%)	72.33 ± 1.45	67.67 ± 3.71	76.00 ± 10.07	68.33 ± 7.17	0.396
Specific growth rate (SGR)	3.20 ± 0.03	2.76 ± 0.41	3.36 ± 0.04	3.14 ± 0.01	0.280
Feed conversion ratio (FCR)	0.50 ± 0.01	0.54 ± 0.04	0.47 ± 0.02	0.51 ± 0.00	0.341
Daily weight gain	0.31 ± 0.01	0.29 ± 0.02	0.33 ± 0.02	0.30 ± 0.00	0.320
Feed efficiency (%)	199.91 ± 5.91	187.40 ± 13.70	213.21 ± 10.59	195.63 ± 1.10	0.316
Condition factor (K)	1.46 ± 0.01	1.60 ± 0.01	1.94 ± 0.02	1.30 ± 0.01	0.095

Source: Field Survey (2021)

A graphical representation of *O. niloticus* growth pattern under various feed treatments is shown in Figure 4.1. For the first 10 weeks, the Nile tilapia grew gradually. From the 12th week up to the 20th week, the growth accelerated. There were no significant differences in the experimental diets' growth trends during the trial ($P > 0.05$). T3 did, however, display somewhat faster growth rates starting at week 14, which were not significantly different from other diets. Figure 4.2 depicts the broken line model. The optimal fish growth weight was determined from this plot to be around 6.5 g with diet T3. The optimal weight was predicted by the equation $y = 7.47 - 0.47x + 0.099x^2$, where x represents the FM substitution level as shown in Figure 4.2. Based on the broken line model, the optimal BSFL inclusion was 50%. However, it is essential to note that the P value was greater than 0.05, meaning this inclusion does not have any significant difference on the growth of tilapia. This optimal BSFL inclusion was lower than in Japanese seabass (*L. japonicus*) (64%) (Wang *et al.*, 2019) but higher than in rice field eel (*Monopterus albus*) (15.78%) (Hu *et al.*, 2020), hybrid tilapia (Nile \times Mozambique) (30%) (Yildirim-Aksoy *et al.*, 2020), Atlantic salmon (*Salmo salar*) (12.5%) (Weththasinghe *et al.*, 2021).

Figure 4.3 shows a linear regression of log body weight on log total length for Nile tilapia fed various inclusion levels of BSFL. With r values close to positive 1 in all diets, there was a significant positive correlation between fish length and weight ($P > 0.05$). The relationship between length and weight is a crucial quantitative factor that provides details on the trajectory of fish growth (Ighwela *et al.*, 2011). Regression coefficients in the current investigation revealed isometric growth trends in all diets with $R > 0.9$. The condition factor provides data on gonadal maturation, feed consumption, and feeding intensity. The fact that the mean condition coefficient (K) was higher than 1 in all diets indicates that the fish are in good health and supports the isometric growth pattern that is advised for fish farms (Kembenya *et al.*, 2014). The high condition factor values might have been caused by the pond's ideal water quality characteristics and the meals' high nutritional standards. These figures also demonstrate that the fish were healthy and that BSFL had no adverse effects on their growth.

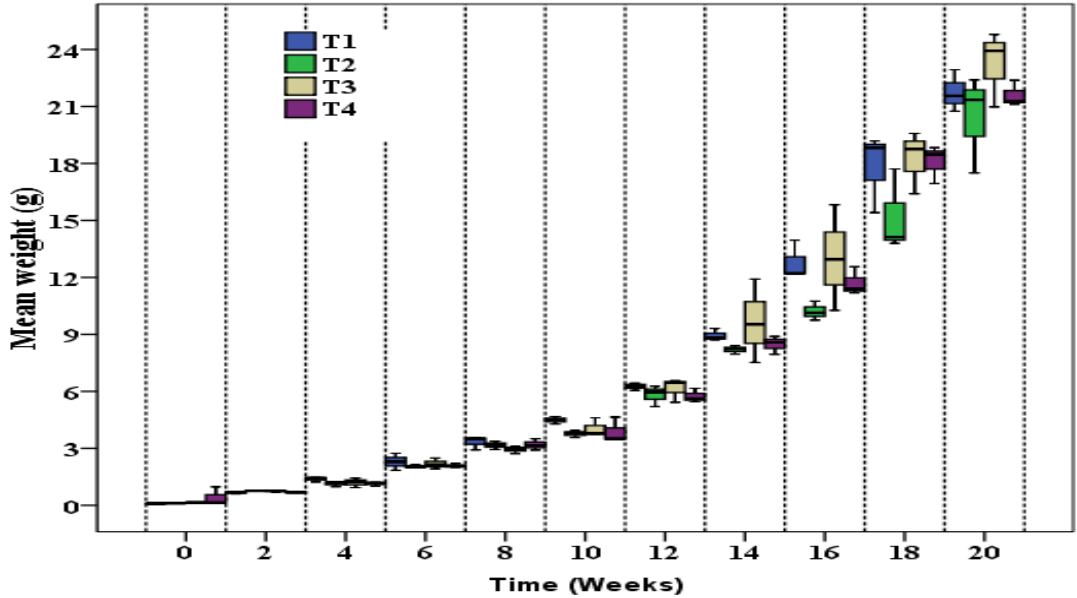


Figure 4.1: Box plots showing growth trend for Nile tilapia fed with experimental diets T1: control diet, T2, T3, and T4 shows replacement of FM with 0 %, 25 %, 50 %, and 75 %, BSFL meal, respectively. Vertical bars indicate the mean \pm standard deviation of the three replicates

Source: Field Survey (2021)

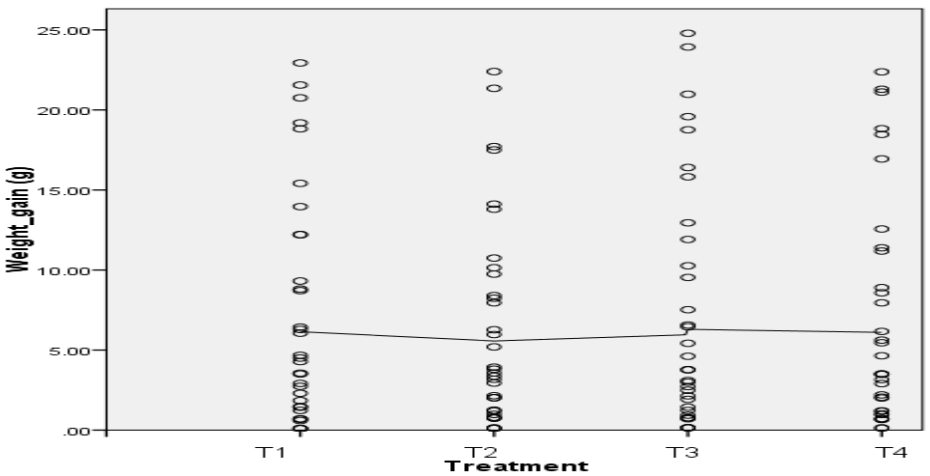


Figure 4.2: Broken line model for Nile tilapia fed with experimental diets. T1: control diet; T2, T3, and T4 represent substitution of FM with 0 %, 25%, 50%, and 75% BSFL meal, respectively. Residual standard error: 49.34, df: 129, Adjusted R²: - 0.015, F statistic: 0.014, P = 0.986.

Source: Field Survey (2021)

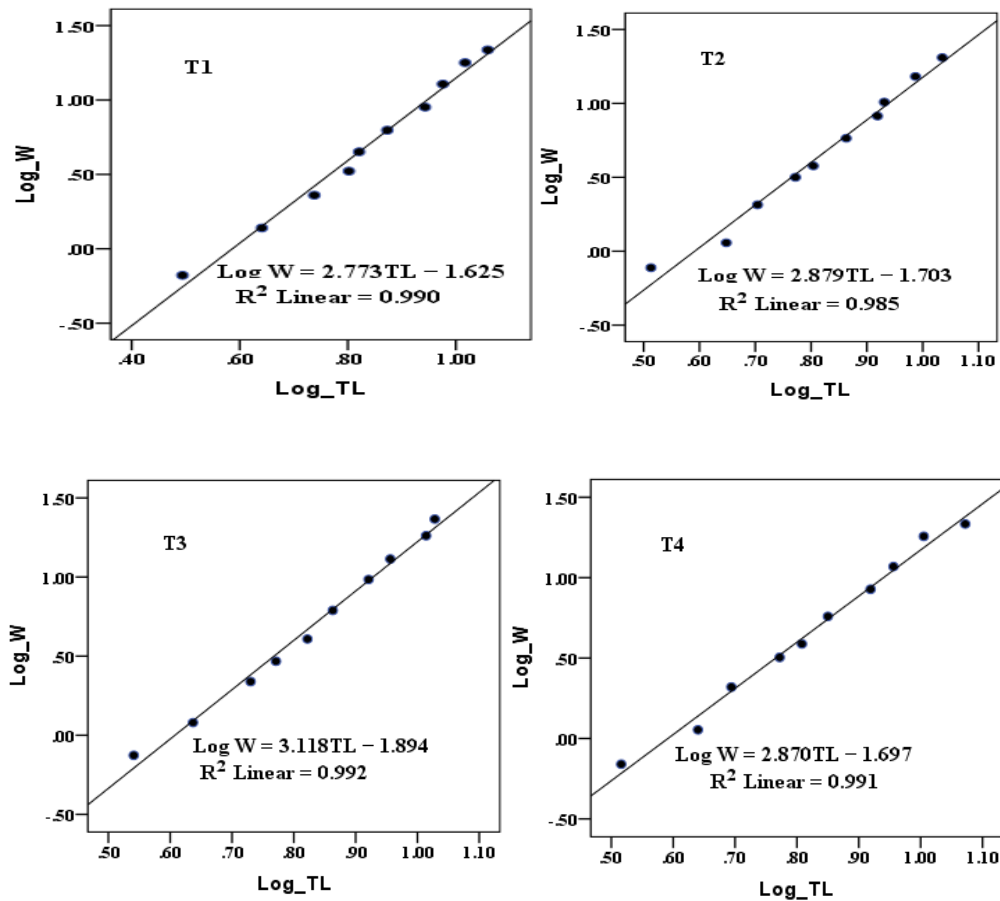


Figure 4.3: The scatter plots of the length-weight relationships for Nile tilapia fed on various diets.

T1: control diet, T2, T3, and T4 denote replacement of FM with 0 %, 25%, 50%, and 75% BSFL meal, respectively. W: wet weight, TL: total length.

Source: Field Survey (2021)

4.2 Economic Efficiency of BSFL in Aquaculture

4.2.1 Economic analysis

From the results of technical efficiency in sub-section 4.1.2, it was found that T3 (50% BSFL) was the most technically efficient based on the FE ratio. However, the most technically efficient diet may not be the most profitable as input and output prices must be considered. Thus, technical efficiency is a necessary condition and not a sufficient condition. This calls for economic efficiency analysis to meet the sufficient condition in identifying the most optimal diet.

Regarding economic analyses, the unit price of formulation of the diet rations decreased gradually as FM was substituted with BSFL. The feed cost per kilogram was highest for fish fed on Diet T1 (Ksh 91.40) and lowest for fish fed on Diet T4 (Ksh 78.76), an equivalent of 13.83% cost reduction as shown in Table 4.3. Compared to diet T1, which served as the control, diet T3 would result in a cost savings of 8.94%. When insect-based feeds were used to replace FM in Nile tilapia diets, previous studies similarly noted a decrease in feed costs (Wachira *et al.*, 2021; Kishawy *et al.*, 2022). The average biomass harvested was highest for fish fed on Diet T3 (0.02324 kg) during the production cycle and lowest for fish fed on Diet T2 (0.02041 kg) during the production cycle.

Table 4.3: Cost Evaluation of Diets

Parameter	T1	T2	T3	T4
Production period (days)	182	182	182	182
Stocking density (pieces)	100	100	100	100
Average production (Kg/182days)	0.02175	0.02041	0.02324	0.0216
Value of fish @ 300 Ksh/kg	6.525	6.123	6.972	6.48
Feed Input (Kg)	13	13	13	13
Cost of feed used (Per Kg)	91.402	87.314	83.233	78.755
Total cost of feed	1, 188.226	1,135.082	1,082.029	1,023.815

Notes: The costs are presented in Ksh (1 USD= 100 Ksh) at the time of the study in January 2021.

Source: Field Survey (2021)

The cost of using each of the four diets is shown by the incidence cost (IC) (Table 4.4), which is defined as the cost of feed required to produce one kilogram of fish (relative cost per kilogram of weight gain). The lower the figure, the more cost-effective it is to utilize that particular feed (Abu *et al.*, 2010). In terms of cost per kilogram of feed, Diet T2 had the highest IC of the treatments (i.e., 4.38 ± 0.13), while Diet T3 had the lowest IC (i.e., 3.61 ± 0.10), suggesting that it would be less expensive to produce Nile tilapia on Diet T3, which had BSFL as the primary

protein source. However, no significant differences ($P > 0.05$) among all the diets were recorded in terms of IC. The economic profit index (PI) was highest for fish fed on Diet T3 (5005.15 ± 143.92) and lowest for fish fed on Diet T2 (4246.64 ± 125.45). The current study recorded the lowest incidence cost associated with a higher economic profit index in fish fed on diet T3. The ECR was lowest for diet T3 (39.12 ± 0.96) and highest in diet T1 (47.70 ± 0.52). The ECR followed the decreasing trend as feed costs, but when BSFL exceeded 50% of the diet, the cost of production of 1 kg of fish (ECR) (40.43 at the 75% level) increased significantly compared to groups of fish-fed control diet (T1) and diets T2 and T3.

Table 4.4: Economic Conversion Ratio, Economic Profit Index, and Incidence Values

	T1	T2	T3	T4	P-value
ECR	47.70 ± 0.52^{abc}	47.15 ± 2.02^b	39.12 ± 0.96^d	40.43 ± 0.69^{cd}	0.004
EPI	4516.15 ± 77.08^a	4246.64 ± 125.45^a	5005.15 ± 143.92^{bc}	4688.18 ± 15.33^{ac}	0.005
IC	4.22 ± 0.07^{ab}	4.38 ± 0.13^b	3.61 ± 0.10^c	3.72 ± 0.01^c	0.001

The values represent mean \pm S.E. Common superscript in the same row shows that the measurements were not statistically different as determined by the unpaired t-test; non-identical superscripts show statistically significant differences ($P < 0.05$).

Source: Field Survey (2021)

Overall, economic efficiency indicates that up to 50% of FM protein replacement with BSFL in Nile tilapia diets is economically feasible. As BSFL quantities increased, the cost of formulating current Nile tilapia diets decreased. Because EPI is a more appropriate metric for evaluating economic profitability because it incorporates output, feed costs, and selling price, the study findings indicate that substituting 50% FM (T3) protein with BSFL has a higher economic return.

CHAPTER FIVE: ACCEPTABILITY OF BLACK SOLDIER FLY LARVAE IN AQUACULTURE PRODUCTION

5.1 Awareness of BSFL in Aquaculture

5.1.1 Descriptive statistics of fish farmers

The socio-demographic and institutional characteristics of the farmers are presented in Tables 5.1 and 5.2. Out of all the respondents, 53.5% were pond farmers while cage farmers made up 46.4%. These results are consistent with previous studies on aquaculture production in Kenya which have reported that the country's aquaculture is dominated by pond-based farming (Mbugua, 2008; Charo-Karisa *et al.*, 2012; Munguti *et al.*, 2014; Munguti *et al.*, 2021). Most of the respondents were males, representing about 73.9% of the farmers. This can be attributed to the male dominance of the aquaculture sector, brought about by factors such as unbalanced gender norms, the high levels of investment and the need for adoption of new technology associated with its development, power relations and education (Kruijssen *et al.*, 2018; Githukia *et al.*, 2020). Majority of the respondents were married (91.9%), with most of them having attained secondary education (52.1%). About 94% of the respondents practiced commercial fish farming. Perhaps, the high number of commercial fish farms is due to the constant push for commercialization of aquaculture in Kenya from both the government and private actors in the sector (Gachucha *et al.*, 2014; Ngwili *et al.*, 2014).

About 54% of the fish farmers were involved in fish farming as their primary occupation, with 30.8% engaged in off-farm business and 15.2% in salaried employment. This implies that most fish farmers had diversified income sources and reduced their vulnerability to risks. Sixty-one percent of fish farmers had not accessed credit facilities to boost their fish farming activities, 56.4% had not accessed extension services, and 80.6% were not members of fish farming groups. The extension service plays a critical role in expanding and enhancing fish output through the relationship between scholars and end-users. Olaoye *et al.* (2016) revealed that enhanced technology adoption might be readily facilitated for groups of fish farmers since it is easier to present the technologies to a group than to an individual.

Table 5.1: Fish Farmer Socio-economic Profile for Categorical Variables

Categorical Variables	Frequency (n)	%(%)
Category of fish farmer		
Fish pond farmer	113	53.6
Cage farmer	98	46.4
Gender		
Female	55	26.1
Male	156	73.9
Education level		
Primary level	40	19.0
Secondary level	110	52.1
University level	61	28.9
Marital status		
Single	16	7.58
Married	194	91.9
Others	1	0.5
Occupation		
Farming	114	54.0
Off-farm business	65	30.8
Salaried	32	15.2
Access to credit		
No	129	61.1
Yes	82	38.9
Access to extension services		
Yes	92	43.6
No	119	56.4
Group membership		
No	170	80.6
Yes	41	19.4

Source: Field Survey (2021)

In accordance with Muddasir *et al.* (2019) findings, the sample respondents were middle-aged fish farmers, with an average age of about 43 years. Concerning years of fish farming experience, the minimum years of experience were found to be 1 year while the maximum was 12 years with a mean of 3.65 years. Regarding the stocking density for ponds and cages, the average stocking density was 3,665 fish per pond/cage. A fish farmer could have just 1 pond or cage and as many as 195. The average number of pond/cage ownership was 8 ponds/cages. The

size and number of fish ponds and cages varied greatly amongst fish farming systems within the research locations. This can be explained by existing farm conditions such as soil type, climatic conditions, labour availability, building materials, investment money, and geographic location. This is consistent with earlier research on pond-based fish farming in Kenya, where most smallholder farmers had 1 to 60 fish ponds (Obwanga *et al.*, 2017). Fish farmers sourced their fish feeds at an average distance of 52.52 km from the fish farms. The study found that fish farmers were feeding their fish on average twice a day.

Table 5.2: Fish Farmers' Socio-economic Profile for Continuous Variables

Continuous Variables	Minimu	Maximu	Mean	Std.
	m	m		Deviation
Age in years of respondent	19	82	43.04	11.674
Years of farming experience	1	12	3.65	2.412
Stocking density per pond/cage	100	25,000	3,664.69	5,606.955
Number of ponds/cages owned	1	195	7.53	20.378
Distance to feed source in Km	1	800	52.52	103.042
Number of times feeding in a day	1	4	1.93	.923

Source: Field Survey (2021)

5.1.2 Level of Awareness of BSFL in aquaculture

About 46% of the respondents were aware of the use of IBFs in aquaculture while 53.60% were not aware of the use of IBFs in aquaculture as in Figure 5.1. Since IBFs are relatively a new concept in Kenya, a greater number of respondents were unaware of their potential role in aquaculture. Various studies (Onsongo *et al.*, 2018; Chia *et al.*, 2019, 2020; Nairuti *et al.*, 2022) have reported that the use of IBFs in animal feeds is still a new practice that is still under experimental and promotion stages. About 61.2% had gotten information about IBFs from the government, indicating the importance of government research institutions and extension services in dispensing information on new technologies and practices to farmers. These results are consistent with those of Quagraine *et al.* (2009) that found that majority of small-scale fish farmers get technical aquaculture information from the government. Majority of respondents

(86.3%) had never seen Black Soldier Fly and only a few (13.7%) had. In a study aimed at assessing BSFL in the diet of African catfish (*Clarias gariepinus*), Adeoye *et al.* (2020) found that majority of fish farmers were aware of organic feed as a supplement for catfish production.

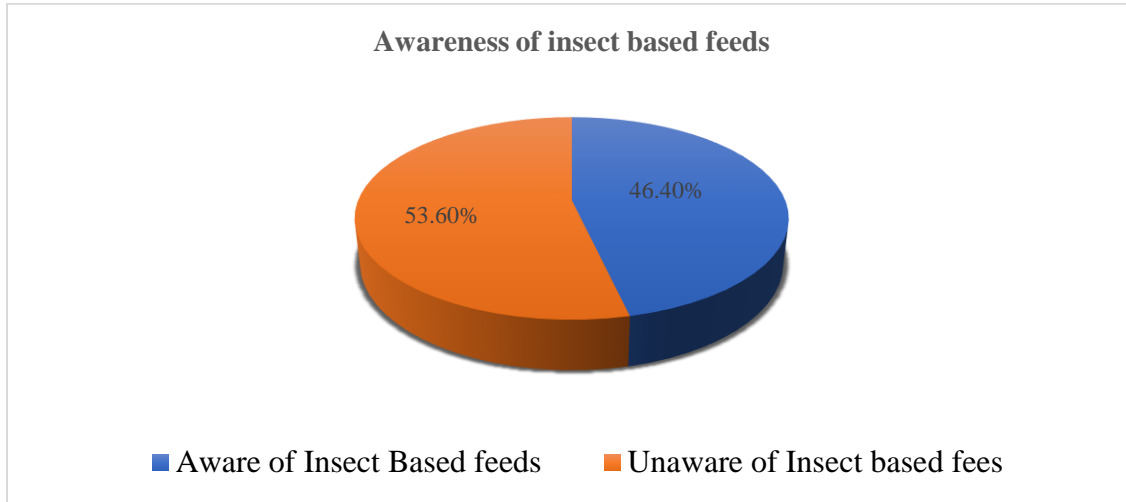


Figure 5.1: Awareness of insect-based feeds among fish farmers
Source: Field Survey (2021)

Internationally, insect research is rising, as evidenced by the recent increase in research and development funding and peer-reviewed publications. The Journal of Insects as Food and Feed was established in 2015 in response to the increased interest in this area. According to the International Platform of Insects for Food and Feed, around 42 European businesses presently produce insect meals, generating 6,000 tonnes annually (Mancuso *et al.*, 2019; IPIFF, 2019). The INSFEED project on integrating insects in poultry and fish feed in Kenya and Uganda (IDRC, 2016), Improving Livelihood by Increasing Livestock Production in Africa (ILIPA, 2017), and GREEiNSECT in Kenya (Roos, 2017) are just a few of the recently funded projects on insect feed for fish production that have been started in sub-Saharan Africa. Numerous other studies have also looked into the potential of insects as food and feed in SSA.

Regarding insect-based feeds in aquaculture, 68.2% had not used IBFs in aquaculture, while only 24.2% had used IBFs, as shown in Figure 5.2. On the other hand, 7.1% were not sure whether they had used or not used IBFs in aquaculture. Generally, out of the sampled respondents, 17.5%

reported to have used termites, 4.3% had used common houseflies, and 0.9% had used mealworms. Only 1.9% reported using BSFL meal as shown in Figure 5.3.

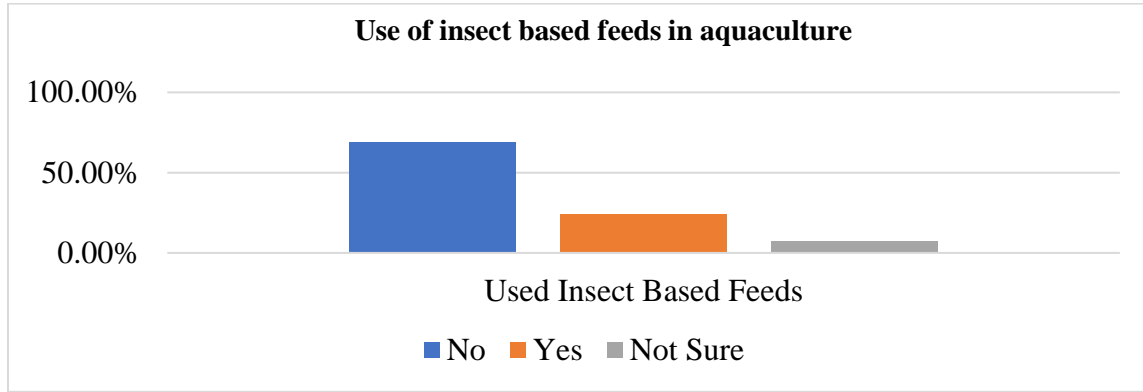


Figure 5.2: Use of insect-based feeds in aquaculture by farmers
Source: Field Survey (2021)

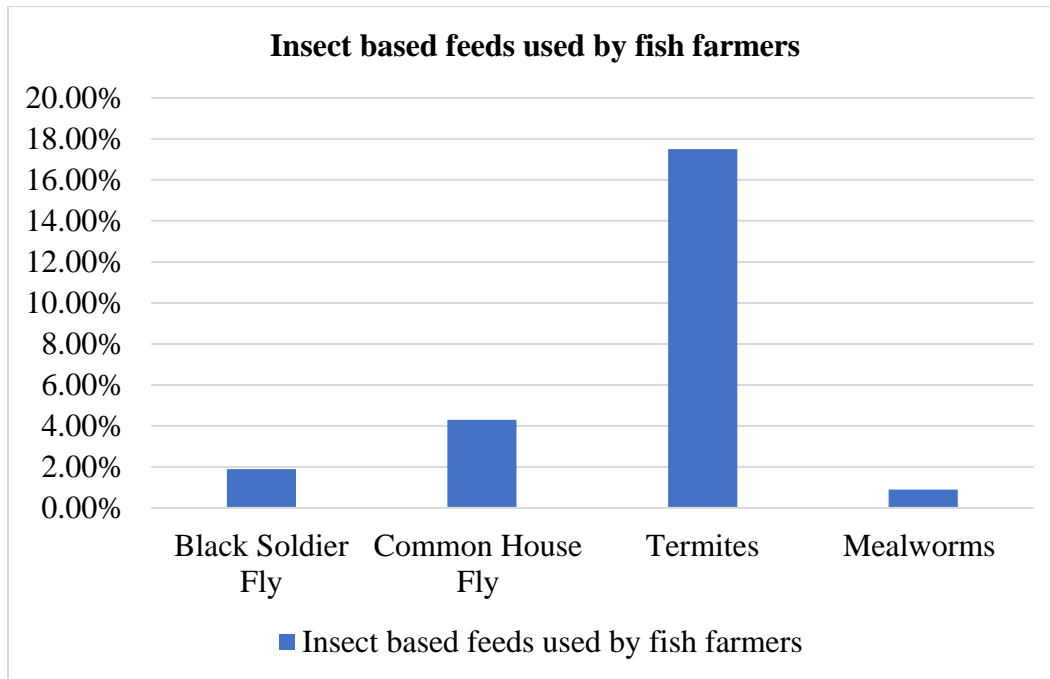


Figure 5.3: Distribution of insect-based feeds used by fish farmers
Source: Field Survey (2021)

This finding is in accordance with previous findings that noted that small terrestrial animals such as earthworms and termites are some of the feed ingredients commonly used by fish farmers in Kenya and locally available (Opiyo *et al.*, 2018). Earthworms have important nutrients and vitamins that are recommended for fish physiology, making them a good choice for small-scale farmers in rural areas where vitamin and mineral supplements are scarce and expensive (Juste *et al.*, 2016; Parolini *et al.*, 2020). Despite the several research studies on the earthworms, worm meal is still not commonly produced commercially nor traded locally particularly in developing countries (Musyoka *et al.*, 2019).

5.1.3 Factors affecting awareness of BSFL among fish farmers

Various factors affect the awareness of BSFL. The study analyzed the effects of such independent variables on the awareness of BSFL. Table 5.3 presents the results of the binary logit regression model to the most critical factors that affect fish farmers' awareness of BSFL. The model's chi-square (χ^2) value of 40.70 and the log likelihood ratio of -54.4179 indicate all the variables in the model significantly influence the probability of awareness of BSFL at $p < 0.01$ level of significance. The Pseudo R^2 value of 0.2722 means that about 27.22% of the decision to adopt BSFL is governed by the tabulated fourteen variables, i.e., the model fits 27.22% to the given data. While this is a low R^2 value, that may warrant low goodness of fit. According to Chabris *et al.* (2008), this is attributed to the field of study. The study justifies that any field of study that deals with humans may have a low R^2 as humans are simply harder to predict than the physical processes. Further, King (1986) points out that the low R^2 does not show that the model is not fit, and conclusions are done based on the significant coefficients regardless of the value.

For the regression analysis using the logit model, thirteen independent variables were used among which four turned out to be statistically significant. Among the independent continuous variables, years of fish farming experience were positive and significantly affected awareness of BSFL ($p < 0.01$). This study revealed that if farmers attain one more year of farming experience, the probability of being aware of BSFL (0.327) increases, as shown by the positive coefficient

value. These findings based on experience level concur with other studies that have reported that farming experience impacts farmers' awareness. They say that having more farming experience makes farmers more aware and embrace better farming practices. Mustafa *et al.* (2019) reported that farmers' knowledge has a positive and significant impact on farmers' awareness of climate change. Ullah *et al.* (2022) also reported that farmers' experience positively affects their awareness of agricultural practices recommended through extension.

Similarly, the impact of distance to feed source in kilometers on awareness of BSFL was positive and significant at $p < 0.05$ level of significance. This implies that with an increase in distance to the feed source by one kilometer, the probability of being aware of BSFL (0.009) increases, as shown by the positive coefficient value. This implies that the further the feed source, such as the distance from the farmers to the feed millers and traders, the higher the probability that the farmer will be aware of the use of BSFL in feeds. This can be attributed to the fact that farmers will be searching for alternative feeds to reduce transportation costs and improve their convenience. Distance between farmers and the feed source is a significant factor in the awareness and willingness to pay for insect-based feeds since it impacts the timely delivery of farm inputs and disposal of farm output (Chirwa, 2005; Mengistu *et al.*, 2016; Chia *et al.*, 2020). In the current study, the closeness of the feed traders to the farmers would determine how they influence the farmers who may buy other conventional feeds from them due to convenience.

The average income earned from fish farming negatively and significantly impacts the awareness of BSFL at $p < 0.01$ level of significance. This implies that the probability of farmers' awareness of BSFL decreases with an increase in the farmers' income. These findings are contrary to the results of (Munyua & Stilwell, 2010), which observed that small-scale farmers with higher incomes have a better capability of being aware of new advancements in farming. Similarly, in a study which sought to analyze the determinants of awareness of devolution of agricultural extension by smallholder farmers in Kenya, Muatha *et al.* (2017) reported that household income had a positive and significant influence on farmers' awareness. The current study's findings could be attributed to the fact that higher-income farmers can afford the conventional feeds and therefore do not seek alternative feeds for their fish.

Table 5.3: Results of binary logistic regression model on fish farmers' awareness of BSFL

Determinant	Coefficient	Std. Err.	z	P>z	dy/dx
County	-0.486	0.343	-1.41	0.157	-0.050
Gender	0.704	0.688	1.02	0.306	0.073
Age	0.027	0.025	1.07	0.287	0.003
Marital Status	-0.999	1.056	-0.95	0.344	-0.103
Education level	0.616	0.415	1.48	0.138	0.064
Farming Experience	0.327***	0.100	3.28	0.001	0.034
logAverageIncome	-0.505***	0.190	2.66	0.008	-0.052
Extension Access	-0.143	0.557	-0.26	0.797	-0.015
Credit Access	0.193	0.665	0.29	0.771	0.020
Group Membership	-1.231	0.918	-1.34	0.18	-0.127
No of Ponds/Cages owned	-0.008	0.012	-0.62	0.536	-0.001
DistFeedSource	0.009**	0.004	2.12	0.034	0.001
Knowledge of Existing Feed	2.667***	0.917348	2.91	0.004	0.280
_cons	-0.539	3.112217	-0.17	0.862	-
LR χ^2 =40.70					
Prob>0.0001					
Pseudo R^2 =0.2722					
Log likelihood= -54.4179					

** and *** indicate statistical significance at $p < 0.05$ and $p < 0.01$ level of significance respectively.; dy/dx =marginal effects

Source: Field Survey (2021)

Among the dummy variables, knowledge about the components of the existing feed was found to positively and significantly influence the farmers' awareness of BSFL at $p < 0.05$ level of significance. This indicates that the more the farmer is knowledgeable about existing fish feeds, the more their probability of being aware of BSFL as a potential component of aquafeeds. This is consistent with previous studies that have confirmed that a person's level of knowledge is critical to awareness of novel farming technologies and practices (Lamarque *et al.*, 2014; Wood *et al.*, 2014; McKitterick *et al.*, 2016; Šūmane *et al.*, 2018).

5.2 Attitudes, Perceptions, and Intention of Fish Farmers to Use BSFL meal in Aquaculture

5.2.1 Measurement Model Analysis

Before the analysis of the measurement model, the four constructs in the proposed model—PEOU, PU, ATT, and INT—were subjected to Harman's single-factor test, as recommended by Podsakoff *et al.* (2003), to address the problem of common method biases. Results revealed that there were six factors whose eigenvalues were greater than 1, and the variation of the first factor was only 31.15% among the unrotated principal component factors, indicating that the common method bias was unlikely a problem in this study (Table 5.4).

Table 5.4: Test for Common Method Bias

Component	Total Variance Explained			Extraction Sums of Squared Loadings		
	Total	Initial Eigenvalues		Total	% of	
		% of Variance	Cumulative %		% of Variance	Cumulative %
1	7.476	31.150	31.150	7.476	31.150	31.150
2	2.262	9.426	40.575			
3	1.885	7.855	48.430			
4	1.373	5.719	54.149			
5	1.293	5.389	59.538			
6	1.150	4.793	64.331			

Extraction Method: Principal Component Analysis.

Source: Field Survey (2021)

While analyzing the measurement model, tests for convergent and discriminant validity were conducted. Convergent validity examines if the concept or latent variable has adequate variance in the observable variables (items). Tests of convergent validity examined Average Variance Extracted (AVE), composite reliability, and factor loadings. To be retained for subsequent analysis, an item must have a minimum loading of 0.70 on the theoretical latent construct assigned. Twelve measurement items (PU1, PU2, PU4, PU5, PU6, PU8, PU9, PEOU4, ATT4, ATT5, ATT6, ATT7) had factor loadings that were below the minimum threshold and were thus disregarded from further analysis. Table 5.5 and Figure 4.7 exhibit the findings of these studies

in their final form. According to Table 5.5's results, factor loadings are all more than 0.6 for every construct. The scales used in this study were derived from previous literature.

Table 5.5: Outer loadings (Factor loadings)

Factor/Indicator	Attitude	Intention to Use	Perceived Ease of Use	Perceived Usefulness
ATT1 BSFL provides a cheap source of protein in fish farming	0.818			
ATT2 BSFL provides nutrients and minerals	0.855			
ATT3 Possibility of rearing BSF guarantees availability	0.882			
INT1, I intend to use BSFL in my fish farm		0.731		
INT2 I would recommend the adoption of BSFL meal for other fish farmers in my region		0.877		
INT3 I would also adopt BSFL meal if the neighboring farmers adopt		0.898		
PEOU1 Use of BSFL feed is a system easy to understand			0.794	
PEOU2 Use of BSFL is a system that would be easy to implement on my fish farm			0.89	
PEOU3 Using BSFL meal would enhance my effectiveness in fish production			0.673	
PU10 Improve organic waste management in the country				0.801
PU3 Lower the ecological footprint of livestock farming				0.835
PU7 Lower our dependence on foreign protein sources				0.700

Source: Field Survey (2021)

According to the results in Table 5.6, both Cronbach's alpha and composite reliability, alternate measures of internal consistency and reliability, revealed that all constructs had strong internal

consistency (Hair *et al.*, 2011). Cronbach alpha values varied from 0.684 to 0.811, composite reliability from 0.823 to 0.888, and extracted average variance from 0.610 to 0.726. The composite reliability estimates were above the recommended threshold of 0.7, and the construct AVEs were greater than 0.5. These findings generally support the measurement model's convergent validity.

Table 5.6: Internal Consistency: Cronbach's Alpha, Composite Reliability, and Average Variance Extracted

Latent Variable	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Attitude	0.811	0.888	0.726
Intention to Use	0.786	0.876	0.704
Perceived Ease of Use	0.701	0.831	0.625
Perceived Usefulness	0.684	0.823	0.610

Cutoff levels: Cronbach's alpha > 0.7 (0.6); composite reliability (CR) = 0.6–0.9; Average Variance Extracted (AVE) > 0.5; n=211.

Source: Field Survey (2021)

Discriminant validity was determined by comparing correlate values to the square root of AVE values. To meet the discriminant validity criteria, the correlations must be less than the square root of AVE (Fornell & Larcker, 1981). Discriminant validity was well established across all constructs, according to the results of the Fornell-Larcker Criterion (Table 5.7).

Table 5.7: Fornell-Larcker Analysis for Checking Discriminant Validity

	Attitude	Intention to Use	Perceived Ease of Use	Perceived Usefulness
Attitude	0.852			
Intention to Use	0.724	0.839		
Perceived Ease of Use	0.579	0.57	0.79	
Perceived Usefulness	0.657	0.675	0.482	0.781

Values on the diagonal (bolded) are the square root of the average variance extracted (AVE), while the off diagonals are correlations.

Source: Field Survey (2021)

The findings suggest that the model's discriminant validity has been established because the HTMT values were significantly lower than 1 (Henseler *et al.*, 2014). The HTMT ratios were all within the cut-off levels below 0.9 except for the HTMT for intention to use, which was precisely 0.9 (Hair *et al.*, 2016) as in Table 5.8.

Table 5.8: Heterotrait-Monotrait (HTMT) Criterion

	Attitude	Intention to Use	Perceived Ease of Use	Perceived Usefulness
Attitude				
Intention to Use	0.900			
Perceived Ease of Use	0.745	0.754		
Perceived Usefulness	0.866	0.882	0.651	

Cut-off level: HTMT<0.9

Source: Field Survey (2021)

5.2.2 Structural Model Analysis

A collinearity test utilizing the variance inflation factor (VIF) was done before the structural model analysis to determine the extent of collinearity threat among the independent variables. The multi-collinearity analysis in the structural model showed no evidence of multi-collinearity ($VIF < 5$) between latent variables, as shown in Table 5.9 with the values ranging from 2.351 to 1.277. None of the independent variables was found to have a significant correlation. To prevent collinearity issues, VIF values of 5 or lower are recommended (Hair *et al.*, 2011).

Table 5.9: Variance Inflation Factor (VIF) values

Variable	VIF
ATT1	1.640
ATT2	1.825
ATT3	1.954
INT1	1.339
INT2	2.166
INT3	2.351
PEOU1	1.397
PEOU2	1.688
PEOU3	1.322
PU10	1.365
PU3	1.364
PU7	1.277
Attitude	2.087
Perceived Usefulness	1.545
Perceived Ease of Use	1.808

Source: Field Survey (2021)

The path coefficients were looked at, and the theoretical correlations were checked after establishing the measurement model's validity and the independent variables' collinearity. The independent components' direct, indirect, and cumulative effects on behavioral intentions—and subsequently on the application behaviour of fish farmers—were applied via path analysis. The variances accounted for by each construct, and the total Variance accounted for were calculated using the determination coefficient (R^2) (Table 5.10).

Since standardized path coefficients were generated, comparing the magnitudes of the coefficients reveals how much each exogenous latent variable impacts the endogenous latent variable. According to the inner model path coefficients, ATT has the greatest impact on farmers' willingness to adopt BSFL (0.411), followed by PU (0.319), and PEOU (0.178). In line with earlier studies (Obiero *et al.*, 2019; McDonald *et al.*, 2016), PU had a stronger relative influence on intention to adopt BSFL than PEOU based on the model path coefficients of 0.319 and 0.178 respectively.

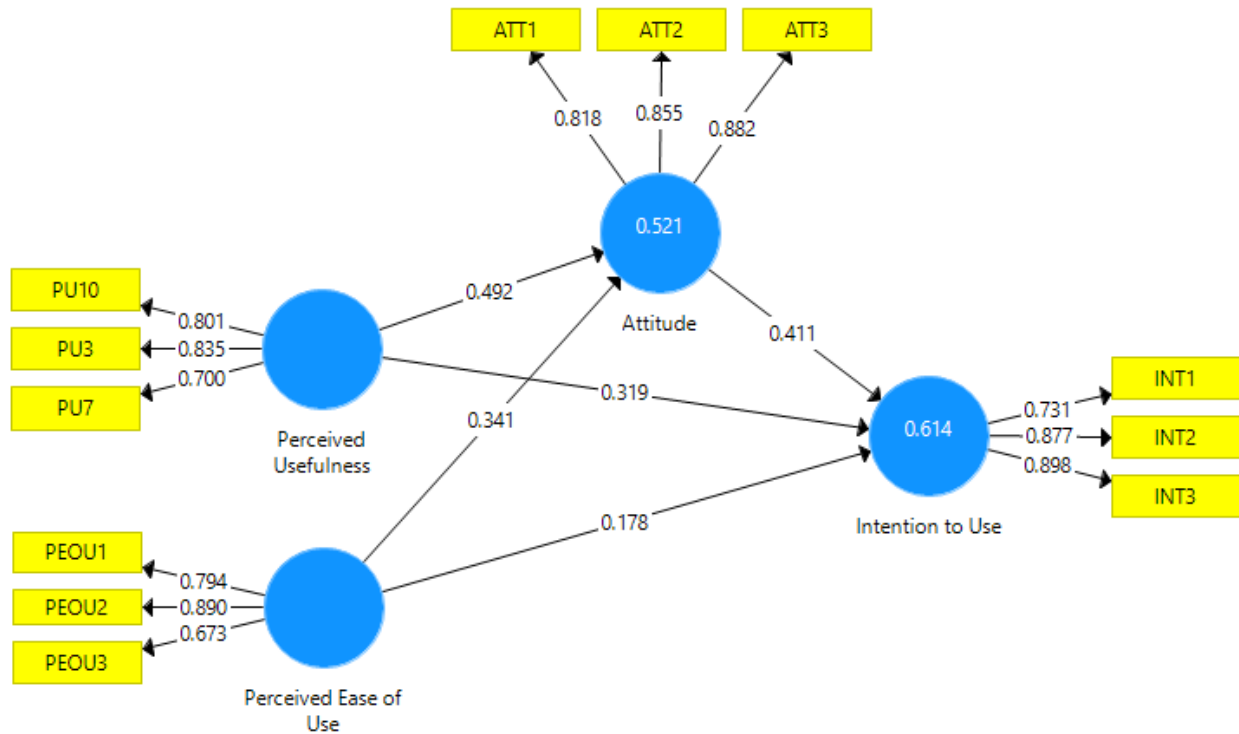


Figure 5.4: Indicator loadings and path coefficients of key behavioral constructs
Source: Field Survey (2021)

The structural model shows the relationship between one variable and another variable with beta (β) and R-squared (R^2) values (Figure 5.4). The results showed that the R^2 for attitude was 0.521, and the R^2 for intention to use BSFL was 0.614. The R^2 value of intention to use could be explained or influenced by 61.4% of the independent variables (ATT, PU, and PEOU), and other factors outside this model influenced the rest.

Using bootstrapping, t-statistics were generated to assess the statistical significance of both the indicators (outer model) and structural model characteristics (inner model). In this study, the path significance is used to assess the hypotheses. At the 5% level, two-tailed t-tests of significance were run, and significance was defined as a t-statistic value greater than 1.96. The outer model likewise used bootstrapping to generate t-statistics, and the results showed that all factor loadings were statistically significant at the 5% level. Figure 5.5 displays the whole set of findings.

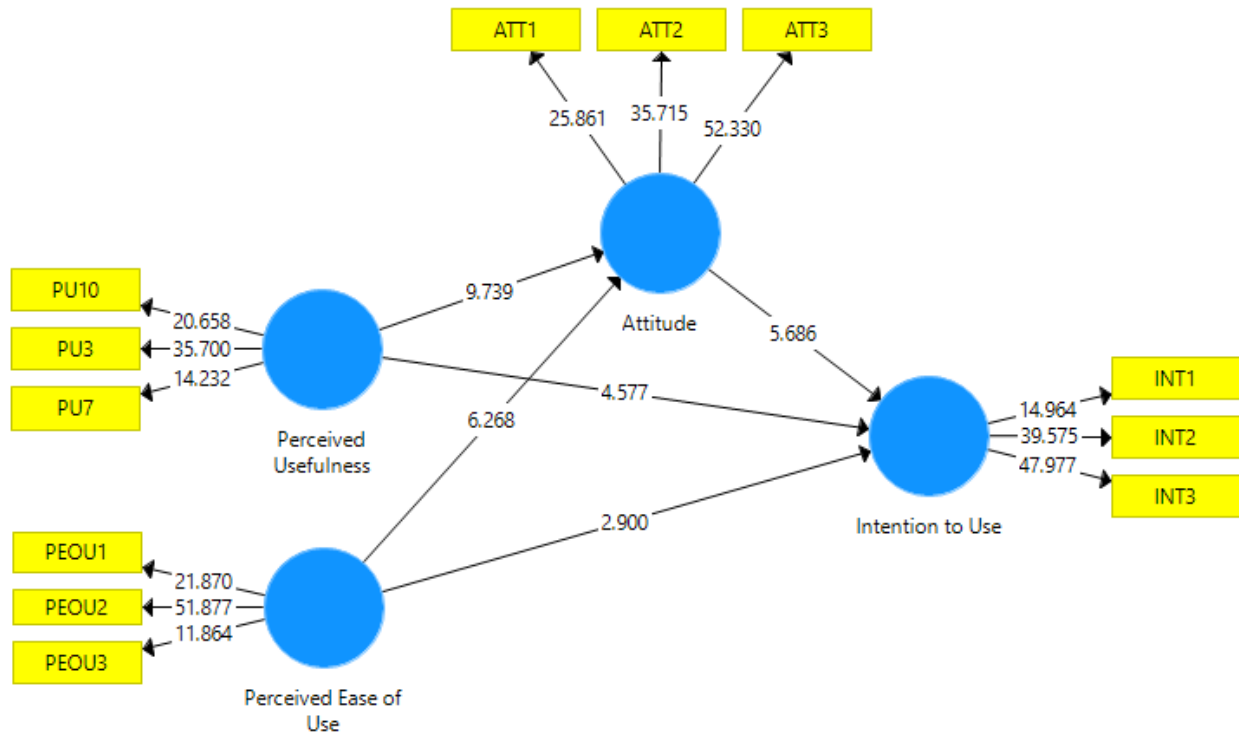


Figure 5.5: Bootstrapping results showing t-statistics
Source: Field Survey (2021)

Finally, the predictive relevance (Q^2) was calculated in PLS-SEM version 3 using the blindfolding procedure. The Q^2 should be greater than zero, according to Hair *et al.* (2017), signifying that the predictor variable has predictive value for the criterion variable. The attitude Q^2 value was 0.370, and the intention to use value was 0.424, indicating that the study model had strong predictive relevance.

5.2.3 TAM Hypothesis Results

Table 5.10 summarizes the results of path coefficients and hypothesis testing. The coefficient of PEOU on ATT was positive and significant, confirming hypothesis H₁ ($\beta = 0.341$, $p = 0.001$), while the coefficient of PU on ATT was positive and significant, confirming hypothesis H₃ ($\beta = 0.492$, $p = 0.000$) as in Table 5.10. As a result, the attitudes of fish farmers were significantly impacted by both PU and PEOU. In turn, behavioral intention was significantly influenced by attitude. The coefficient of ATT on INT was positive and significant, confirming hypothesis H₅

($\beta = 0.411$, $p = 0.000$). This finding on the effect of attitude on intention to use BSFL is similar to the results of Maleksaeidi & Keshavarz (2019), Meijer *et al.* (2015) and Yazdanpanah & Forouzani (2015). This result implies that farmers who had a positive attitude towards using BSFL were more eager to use it in their fish farms.

The coefficient of PEOU on INT was positive and significant, confirming hypothesis H₂ ($\beta = 0.178$, $p = 0.004$). If the BSFL is perceived as easy to use, fish farmers have a higher intention to use it. PEOU reflects fish farmers' confidence in using BSFL. This is in line with the findings of Giampietri & Trestini (2020) and Zhou & Abdullah (2017). The coefficient of PU on INT was positive and significant, confirming hypothesis H₄ ($\beta = 0.319$, $p = 0.000$). This indicates that the more the respondents consider BSFL useful in their fish farm's production conditions, the higher their intention toward adopting BSFL. The results are similar to those of Caffaro *et al.* (2020), who found an association between PU and intention to adopt smart farming technologies. Similar findings were reported by Li *et al.* (2021), who found that PU had a favourable effect on farmers' intentions to participate in vegetable traceability systems. These findings align with TAM's assertion that PU and PEOU are the two main causative factors influencing how technology is adopted and used (Obiero *et al.*, 2019). Bagheri *et al.* (2020) found that cereal farmers' use of biological inputs had both favourable direct and indirect effects of PU on INT. Previous studies have shown that PU directly affects INT, while PEOU directly affects both PU and INT (Flett *et al.*, 2004). Perceived usefulness is vital for changing and reinforcing behavioral attitudes and intentions. It plays a significant role in the model in that perceived usefulness influences behavioral attitude through perceived ease of use and confidence. Adrian *et al.* (2005)'s findings that perceived utility had a positive indirect effect on the intention to use precision agriculture supports the H₇ assertion that PU indirectly influences INT via ATT. However, inconsistent findings regarding its influence on intention have been documented (Venkatesh & Davis, 2000; Venkatesh *et al.*, 2003).

Table 5.10: Results of Path Coefficient and Hypothesis testing, n=211

Path Correlation	Path Coefficients	T Statistics	P Values	Ho Support
Direct Effects				
Perceived Ease of Use -> Attitude (H ₁)	0.341***	6.268	0.000	Supported
Perceived Ease of Use -> Intention to Use (H ₂)	0.178**	2.900	0.004	Supported
Perceived Usefulness -> Attitude(H ₃)	0.492***	9.739	0.000	Supported
Perceived Usefulness -> Intention to Use (H ₄)	0.319***	4.577	0.000	Supported
Attitude -> Intention to Use (H ₅)	0.411***	5.686	0.000	Supported
Specific Indirect Effects				
Perceived Ease of Use -> Attitude -> Intention to Use (H ₆)	0.140***	4.050	0.000	Supported
Perceived Usefulness -> Attitude -> Intention to Use(H ₇)	0.202***	4.493	0.000	Supported

***p< 0.01, **p< 0.05; calculated by bootstrapping (5000 subsamples); Attitude R²= 0.516; Intention to use R²= 0.614; Attitude Q²= 0.370; Intention to Use Q²= 0.424

Source: Field Survey (2021)

5.3 Stakeholders' Perspectives on the Use of BSFL in Aquaculture, Kenya

5.3.1 Sample Characteristics and Participation

In this study, 24 experts from 15 organizations participated in the survey, reflecting a response rate of 60% of those who received the invitation. The professional backgrounds of the participants are shown in Figure 5.6. They comprised research officers and scientists (n=41.7%), fish farmers and managers of fish cages (n=29.2%), academics and lecturers (n=12.5%), fisheries officers (n=4.2%), and other professions (n=12.5%). Males made up 62.5% of the experts (n=15), while females made up 37.5% (n=9). The fact that there were more men than women among the participants may reflect bias among the expert community. The range of professional experience ranged from 3 to 38 years, with an average of 10.58 years and little variation across areas of expertise.

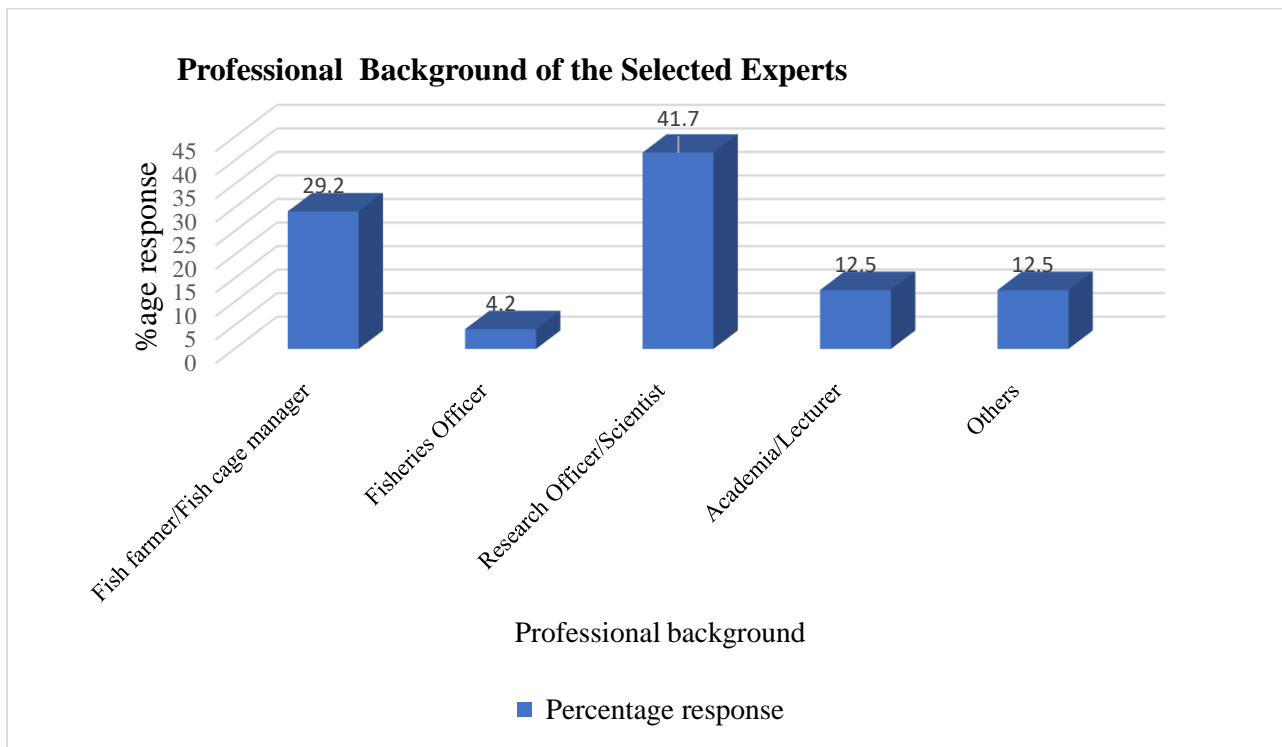


Figure 5.6: Professional Background of the Selected Experts

Source: Field Survey (2021)

The distribution of the institutions/organizations of the respondents is listed in Table 5.11 with the majority of the respondents (29%) from the Kenya Marine and Fisheries Research Institute (KMFRI).

Table 5.11: List of Organizations/Institutions of the Respondents

Name of Organization/Institution	Number of experts interviewed	Per cent
Kenya Marine and Fisheries Research Institute (KMFRI)	7	29%
Jaramogi Oginga Odinga University of Science and Technology (JOOUST)	3	13%
Masinde Muliro University of Science and Technology (MMUST)	1	4%
Jomo Kenyatta University of Agriculture and Technology (JKUAT)	1	4%
African Institute for Development Policy (AFIDEP)	1	4%
Bundesinstitut für Risikobewertung (BfR)	1	4%
Kings Beta Fish Farm	1	4%
Lebed cash marine enterprise Ltd	1	4%
Micro Enterprises Support Programme Trust (MESPT)	1	4%
World Bank	1	4%
University of the Highlands and Islands (UHI)	1	4%
Muga Fish Farm	1	4%
Rio Fish Ltd	1	4%
Lake View Fisheries Ltd	1	4%
Aquaculture private sector	1	4%
Agunja Hatchery	1	4%
Total	24	100%

Source: Field Survey (2021)

5.3.2 Experts' opinions on fish feed challenges and their severity

According to the experts, the most significant fish feed obstacle is the high cost of feeds (87.5%), which is followed by the difficulty in accessing feeds (50%) (Table 5.12). The severity of scarcity of ingredients, lack of knowledge on feed formulation, and substandard feed processing methods were placed third (33.3%). Poor feed quality and high transport, storage, and handling

expenses were rated as the least important issues, at 29.2% and 16.7%, respectively. The primary issues facing fish and aquaculture have been identified as high cost and a lack of availability of feeds in another earlier research conducted in Kenya (Munguti *et al.*, 2014). Shitote *et al.* (2013) concur that the stalling of fish farming in Kenya has led to household food insecurity and a low contribution to livelihoods due to a lack of commercially made feeds and the adoption of low pond management techniques. Munguti *et al.* (2021a) claim that the use of inappropriate formulations is a major problem in Kenya. His research shows that although some fish farmers feed with grow-out feeds created for other species, others use commercial grow-out formulations with an excess amount of dietary protein. According to an earlier study by Munguti *et al.* (2021b), many of the feed ingredients used in farm-made tilapia diets are insufficiently milled and do not adhere to appropriate standards. Due to the components' poor binding properties, low ingestion rates and high economic feed conversion ratios are the outcomes. The success of small- to medium-sized fish farming operations is also attributed to healthy markets, the availability of feed, finance, and transportation, as well as a profit-driven mentality (OECD, 2010).

Table 5.12: Experts' opinions on fish feed challenges and their severity

Fish feed challenges	Severity			
	Not a problem (%)	Minor Problem (%)	Big Problem (%)	Very big problem (%)
High cost of feeds	0	4.2	8.3	87.5
Inadequate access to fish feeds	16.7	12.5	20.8	50.0
Shortage of ingredients	8.3	4.2	54.2	33.3
Inadequate knowledge about feed formulation	8.4	33.3	25.0	33.3
Poor feed processing technologies	8.3	20.8	37.5	33.3
Poor feed quality	8.3	8.3	54.2	29.2
High transport, storage, and handling costs	8.3	50.0	25	16.7

Source: Field Survey (2021)

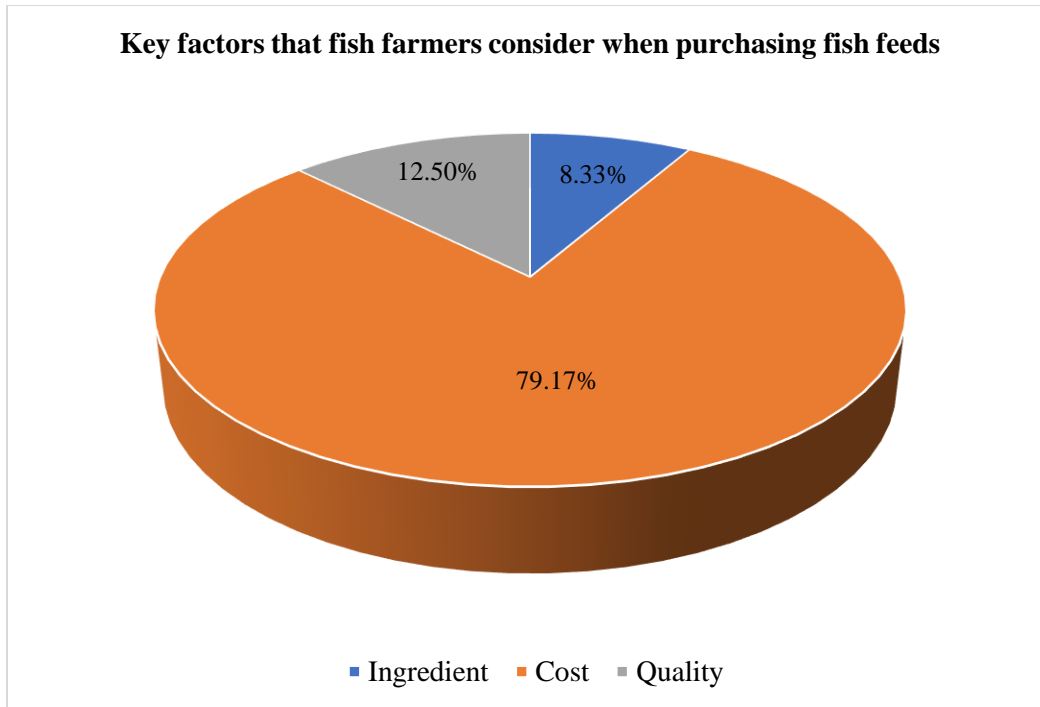


Figure 5.7: Driving factors to promote adoption of BSFL in fish production
Source: Field Survey (2021)

When given the option between ingredient, affordability, and quality when purchasing fish feed, experts were questioned about what they believed to be important. The outcomes are shown in Figure 5.7. Only 8.33% of the 24 experts indicated ingredients, which may be because most fish farmers are unaware of the contents in current fish feeds. Out of the 24 experts, 79.17% said that farmers chose cost as the main determining factor when buying feeds. Statistical analyses revealed that experts concurred on the most important aspect that fish farmers consider when choosing fish diets ($\chi^2= 8.515$, $P=0.744$).

5.3.3 Familiarity with Insect-Based Feeds

The experts were questioned on their familiarity with insect-based diets in Kenya. According to the results, the majority (95.8%) of respondents had heard about Kenya's use of insect-based feeds in aquaculture. The experts' responses were consistent across all professional backgrounds ($\chi^2= 2.534$, $P=0.639$). Additional research revealed no noticeable difference in the expert's knowledge of insect-based feeds in Kenya depending on the years of experience ($\chi^2= 11.478$,

P=0.404). Therefore, participants in this study were familiar with the idea of BSFL meal in aquaculture, demonstrating a high degree of familiarity with the subject under investigation. According to earlier research by Ssepuuya *et al.* (2019), fish farmers' and traders' favourable perceptions of insects' use in aquaculture were strongly influenced by their familiarity and understanding of their utilization. As shown in Figure 5.8, more than 50% of the experts agreed that feeding fish insects is a common agricultural technique, whereas more than 10% thought feeding fish using insect-based diets was abnormal. Earlier investigations also reported that freshwater species such as Nile tilapia and marine fish naturally eat insects (Howe *et al.*, 2014; Whitley & Bollens, 2014; Njiru *et al.*, 2004).

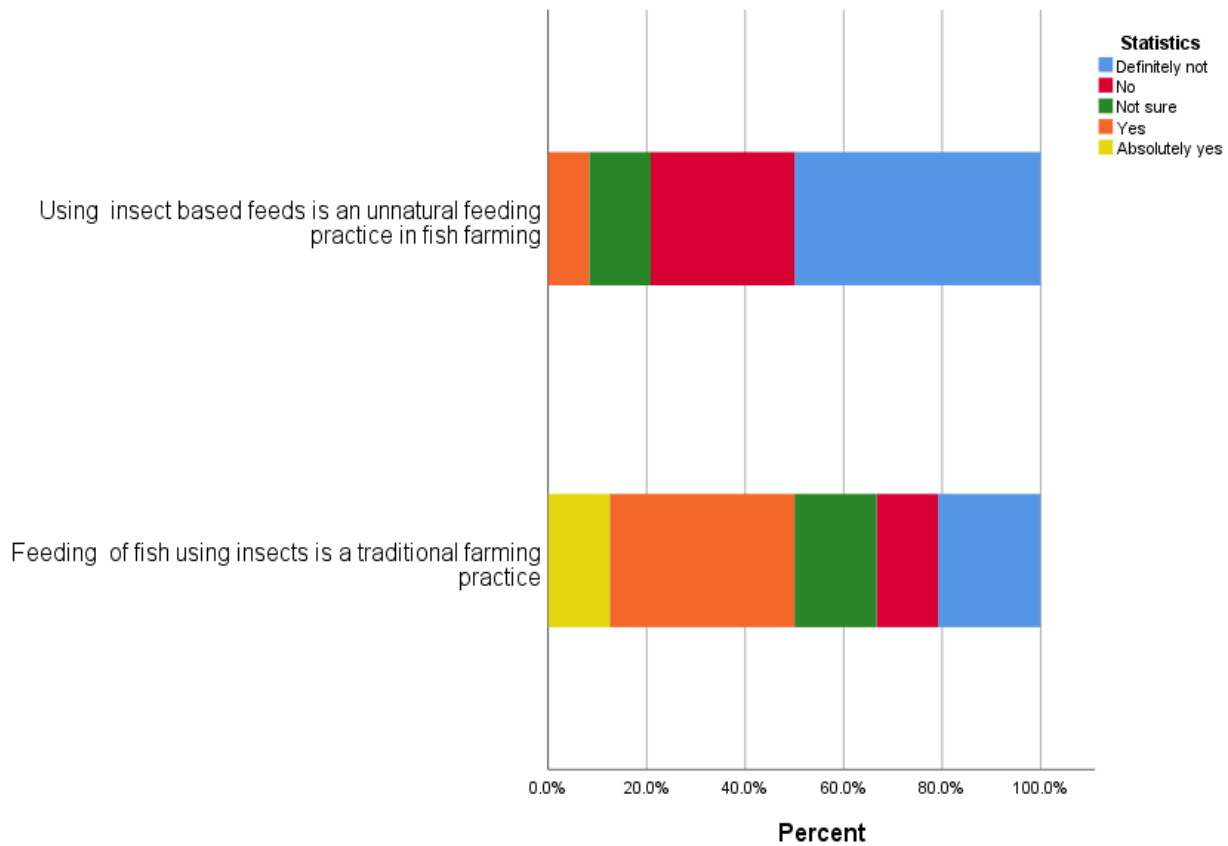


Figure 5.8: Expert's opinion on feeding insect-based feeds on fish
Source: Field Survey (2021)

5.3.4 Perceived Benefit and Perceived Risks of the Use of Black Soldier Fly Meal in Aquaculture

Table 5.13 summarizes the findings of the statements indicating the perceived benefit and risks of using BSFL in fish feed. To elicit responses from the experts, a Likert scale with scales ranging from (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree was employed.

Table 5.13: Perceived Benefits and Perceived Risks of the use of Black Soldier Fly Meal in Aquaculture

Perception Statements	Mean	Std. Deviation	Cronbach Alpha
Perceived Benefits			
Could allow organic waste to be better valorized	4.17	.917	0.911
Could allow sustainability to be improved	4.29	.908	
Could allow the production of enough fish for the world population	3.92	1.060	
May reduce the price of feed and fish production	4.42	.929	
Can improve society's acceptance of fish production	3.50	1.103	
Reduction in reliance on fishmeal	4.33	1.007	
Better fish nutritional value	4.04	1.083	
Perceived Risks			
May cause allergic reactions in humans	2.29	.859	0.748
May cause allergic reactions in fish	2.00	.780	
Can impact biodiversity if the BSFL are accidentally released	2.71	1.268	
May introduce microbiological contamination in the fish feed supply chain	2.46	1.141	
BSFL farming can increase competitiveness with other agricultural activities	3.04	1.268	

Source: Field Survey (2021)

The Cronbach's alpha for benefit statements was 0.911 showing that the scores for the various benefit statements can be summed up into an overall score. The overall mean benefit score computed was 4.104 and significantly higher than the average point of the scale ($t=25.045$,

$P < 0.000$). The strongest perceived benefits were that the use of insects in the fish feed may reduce the price of feed and fish production (mean=4.42), could reduce overreliance on fishmeal (mean=4.33), could allow sustainability to be improved (mean=4.29), could allow organic waste to be better valorized (mean=4.17) and could improve the nutritional value of fish (mean=4.04). The study participants were least convinced that BSFL could allow the production of enough fish for the world population (mean=3.92) and can improve society's acceptance of fish production (mean=3.50), however, these were still positive agreements.

The Cronbach's alpha for risk statements was 0.748 showing that the scores for the various risk statements can be summed up into an overall score. The overall mean risk score computed was 2.500 and significant ($t = 16.022$, $P < 0.000$). The strongest perceived risks were that BSFL farming can increase competitiveness with other agricultural activities (mean=3.04) and use of BSFL could impact biodiversity if they are accidentally released (mean=2.71), which generally indicated that the experts on average neither agreed nor disagreed that the issues constituted a potential risk. All other mean risk perceptions were below the mid-point scale, indicating that the study participants on average disagreed that the issues constituted potential risks.

A paired sample t-test ($t = 6.350$; $P < 0.001$) revealed a significant difference between the scores. Researchers, therefore, concluded that fish farmers have a significantly higher perception of the benefit of BSFL in aqua feed than they do of the risk. In conclusion, benefits perceptions were generally stronger and more outspoken than risk perceptions. Thus, there is a high degree of acceptance of BSFL meals among the experts. These findings are congruent with that of Verbeke *et al.* (2015) who found the perceived benefits of using insects as feed to outweigh perceived risks and concerns as determinants of insect feed acceptance. Similarly, Opong (2017) found the perceived benefits of BSFL-based fish feed to outweigh the perceived risks among farmers in Ghana.

5.3.5 Important Considerations when Legalizing BSFL Meals in Kenya

Kendall's coefficient of concordance (W) was used to gauge the degree of agreement among the factors the experts identified and prioritized when Kenya considers legalizing the use of BSFL

feed in aquaculture. The results are shown in Table 5.14. The coefficient of concordance (W), which measures how well experts agree, was assessed to be 0.156 overall and was statistically significant at 1%. This indicates adequate proof of the experts' agreement on the listed factors. As a result, the ranking of the crucial factors as provided by the professionals is justified.

Table 5.14: Ranking of important Consideration when legalizing BSFL Meal in Kenya

Variables of importance	Mean Rank	Rank Position
Sanitary policy and inspection	7.25	1
Feed safety	7.23	2
Environmental impacts	6.69	3
Fish quality	6.65	4
Feed prices	6.48	5
Traceability	6.06	6
Profitability	5.65	7
Fish farmers acceptance	5.25	8
Efficient use of resources	5.17	9
Labelling of the end product	5.15	10
Perception of the fish industry	4.44	11

Kendall Coefficient of Concordance (W^a)= 0.156; Chi-square=38.254; DF=10 P< 0.001);

Cronbach's Alpha (α) =0.839. The rankings were relative importance on an ordinal scale of 1 (Not important at all) to 5 (Very important).

Source: Field Survey (2021)

In order of importance, sanitary policy and inspection was ranked top, followed by feed safety, environmental effects, and fish quality, which came in at numbers two, three, and four, respectively. Consideration of the fish industry's perception was deemed the least important when deciding whether to legalize BSFL in aquaculture. Likewise, a previous study suggests that the production limitations associated with using insects as feed include the possibility that insects may have antinutrient properties, food safety issues, disease vectors, or pesticide residues (Makkar *et al.*, 2014; van Huis, 2016; Dobermann *et al.*, 2017). Government rules and regulations are required since insect farming also requires standardization and quality control (Han *et al.*, 2017).

Given favourable regulation and market approval, feed makers are willing to integrate insects into their feed mix (AllaboutFeed, 2015). The Malawian fish industry may turn around and become more productive if insect meal is introduced to fish feed in place of soybean and fish meal, according to a study by Mulumpwa (2018). Insect meals must go by the regulatory restrictions associated with PAP regulations to be safe for use as components of fish feed since they are recognized as processed animal protein (PAP) (Belghit *et al.*, 2019).

In aquaculture, sanitation and inspection are crucial. Embay *et al.* (2015) observed that when grains are crushed and feed pelleted, the feed can become contaminated with fungus spores during processing. Some feed storage and processing procedures, such as ambient temperatures above 27°C, humidity levels exceeding 62 per cent, and feed moisture levels over 14 per cent, may lead to mycotoxin formation (Mahfouz & Sherif, 2015). The subjection of fish to mycotoxigenic fungus may result in reduced growth rate, decreased immunological reactivity, liver damage, and a persistent and progressive drop in the quality of produced fish stock, providing severe problems to aquaculture (Fallah *et al.*, 2014).

Any new feed product must be safe, widely accepted, and free of contaminants, including diseases, germs, chemicals, toxins, and heavy metals (DiGiacomo & Leury, 2019). These factors must be considered for each type of insect raised in captivity and each species of insect-fed insect. Because they don't deposit their eggs on decomposing organic materials and don't eat rotting materials as adults, BSFs are not disease carriers (van Huis *et al.*, 2013). Cd and Pb were significantly accumulated by BSFL larvae that were fed on heavy metal-infused substrates (As, Cd, Pb, Hg, Cr, and Ni), whereas as was present in the same quantity in the larvae as was shown in the rearing material (Cai *et al.*, 2018). The ability of BSFL larvae to consume mycotoxins and pesticides in feed and remove the poisons such that growing larvae/mealworms do not retain the toxins has been demonstrated (Cai *et al.*, 2018, Van Der Fels-Klerx *et al.*, 2018). Additionally, BSF larvae kept on pesticide-spiked substrates did not have chemicals deposition in them (chlorpyrifos, chlorpyrifos-methyl, and pirimiphos-methyl) (Purschke *et al.*, 2017).

Marijani *et al.* (2017) noted that although fish feed quality standards exist in the East African countries including Kenya, standards for the manufacture, distribution, storage and handling of ingredients are either non-existent or not strictly regulated by law. Proper screening of substrates for their protein content can as well contribute to improved larval protein quantity and quality (St-Hilaire *et al.*, 2007; Tschirner and Simon, 2015). The type of insect rearing substrate affects the insects' amino acid composition. For example, black soldier fly larvae raised on swine manure had a different amino acid composition compared to those raised on cow manure (Newton *et al.*, 2005).

Feed costs should also be considered. Dried BSFL is priced between USD 1.1 and 1.4 per kilogram on the open market (Tanga *et al.*, 2021). According to a comparison of break-even sales prices of feeds that use BSF meal as a protein source with those of traditional feeds in West Africa, insect meals are competitive with feeds based on fishmeal as a protein source (Roffeis *et al.*, 2018).

The experts also regarded environmental effects as a crucial consideration while evaluating the legislation of BSFL. The production of insects for food is considered more environmentally friendly than the protein-rich soybean meal and fishmeal used as aquaculture feed. This is in line with prior research from Smetana *et al.* (2019), who found that generating 1 kg of BSFL used less water, created less CO₂, and required less land than producing soybean meal and fishmeal. Concerns have also been raised regarding the possibility of edible insects escaping into the environment and invading native ecosystems and agricultural systems in non-native countries. The results of Thrastardottir *et al.* (2021) in Iceland, where an environmental risk assessment for BSF was carried out prior to receiving an import and trial authorization from Icelandic authorities, are comparable. The results indicate that BSF has a minimal impact on the local insect environment. Since BSF is a tropical species that cannot survive in Iceland's subarctic climate, it is implausible that a wild population would thrive in an escape.

5.3.6 Driving factors to promote adoption of BSFL in fish production

The study sought opinions on potential motivating reasons to encourage the implementation of BSFL in fish farming. Figure 5.9 displays a rating overview of the potential driving forces.

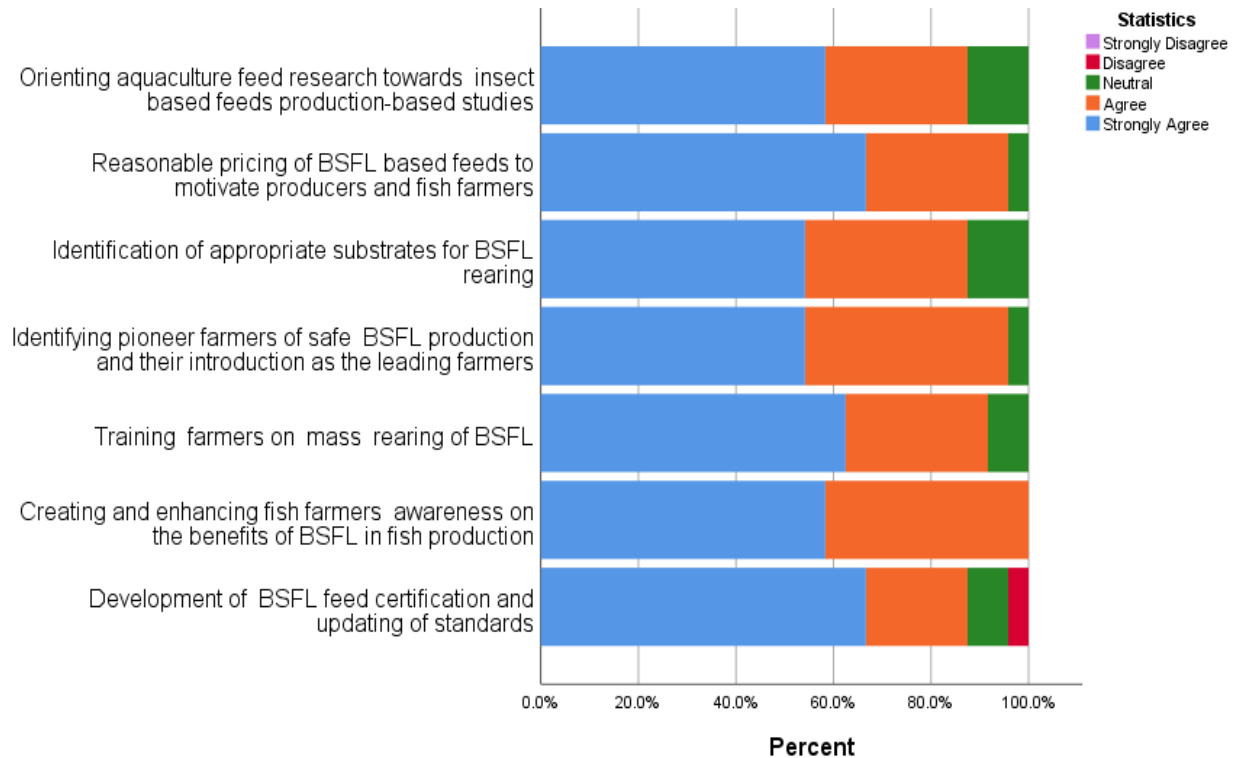


Figure 5.9: Driving factors to promote adoption of BSFL in fish production
Source: Field Survey (2021)

By summing the percentages of "agree" and "strongly agree," it was evident that raising fish farmers' awareness of the advantages of BSFL in fish production (at a rate of 100%) was the most significant driving force. This was followed by identifying pioneer farmers who produced BSFL safely and introducing them as model farmers (at a rate of 95.9%). Reasonable pricing of BSFL-based feeds to inspire producers and fish farmers (at a rate of 95.9%). The results corroborated those of Khaemba *et al.* (2021). They showed that better consumer education and evidence-based arguments for BSFL-based feed's advantages would increase consumer perception and encourage adopting this quickly evolving and novel technology. To fulfil the demands of an expanding human population, efforts to raise awareness of the potential role of insects as a creative food or feed resource have gained traction (Van Huis *et al.*, 2013). According to Van der Poel *et al.* (2013), feed costs can make

up to 80% of a farmer's total production costs, leaving farmers with limited resources with highly slim profit margins. Therefore, BSFL's affordable price will be essential to lowering production costs and boosting small farmers' profitability.

CHAPTER SIX: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The main goal of this study was to investigate the viability of employing BSFL as a feed input in Kenyan aquaculture production. More specifically, the effect of partially replacing dietary FM with BSFL based-meal on technical efficiency and economic efficiency in the production of Nile tilapia and determining the social efficiency (acceptability) of BSFL in aquaculture production. The first objective sought to evaluate the technical efficiency of BSFL in aquaculture production. The proximate composition has shown to be a fundamental tool for identifying suitable ingredients and tracking nutritional profiles through diet formulation toward producing nutritious fish. All growth parameters recorded in this study did not indicate any significant difference. Feed Efficiency (FE) and Feed Conversion Ratio (FCR) were the two major indicators of technical efficiency in this study. Diet T3 with a 50% BSFL inclusion level had the lowest FCR (0.47 ± 0.02) and highest FE (213.21 ± 10.59) compared to the control diet T1. The higher the FE, the greater the feed use efficiency, while the more significant the FCR, the greater the feed use efficiency. The average biomass harvested was highest for fish fed on Diet T3 (0.02324 kg) during the production cycle. The study revealed that a 50% BSFL inclusion level could replace FM in experimental Nile tilapia diets under the experimental conditions employed without adversely affecting growth performance, reflecting higher technical efficiency.

The economic efficiency analysis in objective two indicated that BSFL diets were cheaper than FM diets, with a cost savings of 13.83% in diet T4 compared to control diet T1. Therefore, economically diets with higher inclusion levels of BSFL performed better than diets with higher FM quantities. This is because FM was nearly twice as expensive per kilogram as BSFL. Overall, the present study suggests that insect protein derived from BSFL could be an option to make Nile tilapia feed formulations more economically viable with a cost reduction of 8.94% for optimal output. Therefore, Nile tilapia diets may substitute up to 50% of FM protein with BSFL without compromising growth performance, feed utilization, or economic efficiency.

On the social efficiency analysis (acceptability) performed under objective 3, about 46.40% of the respondents were aware of using IBFs in aquaculture. In comparison, 53.60% had not

heard about the use IBFs in aquaculture, with only 1.9% reported having used BSFL meal in aquaculture, translating to low levels of awareness and use. Knowledge about components of existing feed, distance to feed sources, and years of fish farming experience positively and significantly affected the understanding of BSFL in aquaculture. The study's findings on the perceptions, attitudes, and intentions of fish farmers to accept BSFL in the production of Nile tilapia showed that attitude was the main factor influencing intention, followed by perceived usefulness and then perceived ease of use. Since attitude had the greatest influence on intention, fish producers with positive attitudes toward BSFL are more likely to adopt it in fish production because they have a higher intention. This study offers strong empirical insights into a model for analyzing technology-acceptance-model related factors that affect farmers' intentions to use BSFL to increase their fish productivity. This means that the findings provide a strong foundation for application in a variety of situations and theoretical analyses in different research disciplines. This study gives solid empirical insights into a model for examining technology-acceptance-model associated aspects that impact farmers' aspirations to employ BSFL to improve their fish output. The results of this study can be used by actors along the fish feed value chain to understand the technology adoption process. Previous TAM adoption research has mainly concentrated on quantifying adoption predictions rather than investigating how social variables interact and impact attitudes and actions. This study shows how the TAM may be used qualitatively to better understand farmer decisions, in this case, the use of BSLF meal. The study illustrates how the TAM may provide an evidence-based framework for qualitatively investigating the intentions and behaviour of fish farmers. This technique has yielded fresh insights into farmer decision-making, which will help to improve future extension development.

From the Delphi study, there was a consensus among the stakeholders toward BSFL in aquaculture. This consensus ranged from nutritional, economic, legal, and marketing aspects. The majority of experts stated that the biggest problems with fish feed in Kenya are the high cost of feeds (87.5%) and a lack of access to feeds (50%) Additionally, more than 79% of the experts (or experts) stated that cost is the primary consideration for farmers when purchasing feeds. Nearly all experts (95.8 per cent) are aware that insect-based feeds are used in aquaculture in Kenya. When it comes to the alleged benefits and risks of using BSFL in aquaculture, the positives were frequently more pronounced than the worries. As a result of

these findings, it shows that positive sentiments of BSFL in aquaculture are uniform and independent of stakeholder group or field of expertise.

6.2 Conclusions

The key findings from the investigations conducted for this study are as follows: Replacing 50% BSFL with FM in diets of Nile tilapia is technically efficient as diet T3 had the lowest FCR and the highest FE. Therefore, increasing technological efficiency in fish production is essential for creating more sustainable aquaculture on the economy, society, and environment levels.

Regarding economic efficiency, diets with 50% BSFL inclusion (T3) resulted in a lower production cost, with the lowest economic conversion ratio (Ksh 39.12 per kg of fish produced) obtained from diet T3. At the same time, the maximum economic profit of Ksh 5005.15 was also obtained on diet T3. Diet T3 would result in a cost reduction of 8.94% compared to the control diet T1. As a consequence, substituting FM with BSFL at 50% would result in not only cheaper diets but also superior economic returns. Given that the current market price of FM is high and extremely competitive due to scarcity and recurrent prohibitions in Kenya due to overfishing substituting BSFL will drastically cut the cost of aquafeed production for tilapia with well-balanced nutritional content.

BSFL was suitable for the production of fish. It was thought that the inclusion of insects in the fish feed might lower costs associated with feeding animals and raising fish, lessen dependency on fishmeal, and increase the sustainability of fish production. The model supports all seven of the TAM's assumptions. The PLS-SEM results, therefore, support the specified associations within the theory and give additional evidence of the significant importance of the TAM model utilized in this investigation. This shows that the TAM constructs directly and indirectly affected Kenyan fish producers' intentions to BSFL in aquaculture. Because attitude has the most significant impact on intention, fish farmers with good views regarding BSFL are more likely to adopt it in fish production because they have a higher intention to conduct this action. Despite promising results, BSFL meal is not widely available in the market hence the need for policy intervention.

This study adds new knowledge by analyzing the socio-psychological factors influencing fish farmers' adoption intention-behaviour in insect-based feeds in aquaculture, especially in

Kenya. It also demonstrates the technical and economic efficiency of BSFL diets in Nile tilapia production.

6.3 Recommendations

The following recommendations are made on the present study:

1. Using BSFL in Nile tilapia is quite promising and cost-effective. Because BSFL is not widely available, more research is required to encourage its growing using other substrates and processing techniques. Its commercialization is also necessary to realize its full potential as an aquaculture protein element.
2. To improve fish farmers' attitudes, it is necessary to increase awareness of and advocate for the use of BSFL in fish farming. Through various publicity channels and media, relevant government departments can raise awareness and influence of BSFL feeds. For example, public programs such as training trainer's modules for extension agents and model farmers should be implemented to help them understand and realize that using BSFL in fish production can be of great economic benefit to them. Interventions, including experimental demonstrations, are essential for educating farmers about the value of BSFL use in aquaculture and lowering their resistance to BSFL acceptance.
3. Strategic use of behavioral-change interventions such as information provision, persuasion, and motivation can be explored to strengthen fish farmers' attitudes toward using BSFL.
4. BSFL as a sustainable protein source in aquaculture might play a part in achieving food security and may participate in the solution of its problems, considering the legislative issues such as precautions to prevent the accumulation of some substances that are harmful to fish consumers in the insect biomass.

6.4 Suggestions for further research

This study suggests that investigating the technical and economic efficiency of using BSFL in aquaculture should be continued at KMFRI and extended to other fish species apart from Nile tilapia.

Second, this study advances knowledge in this area by examining the critical theoretical and practical ramifications of fish farmers' plans to employ BSFL in fish production. Future

research could focus on how socio-demographic variables affect variance in attitudes, perceptions, and intentions concerning the adoption of BSFL. For example, it would be interesting to study the effect of the scale of production or cultural differences on farmers' actual adoption and decision behaviour in Kenya and elsewhere in the world.

Future studies should also focus on analyzing the factors that influence the adoption of BSFL, using a sample of fish farmers who adopt and do not adopt BSFL, and explore the same sample in the future to verify the characteristics of farmers who adopted BSFL. Future research should build on these results. It would be best if it took the form of in-depth interviews or workshops with important participants and an emphasis on sustainability issues.

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APPENDICES

APPENDIX 1: LETTER OF INTRODUCTION

No.....

Dear Sir/Madam

I am a post-graduate student at Jaramogi Oginga Odinga University of Science and Technology. In partial fulfillment of the requirements for the conferment of the Doctor of Philosophy of Food Security and Sustainable Agriculture degree, I am conducting research on **“Socio-economic Efficiency of Black Soldier Fly Larvae (*Hermetia Illucens*) Meal as an Alternative Feed in Nile Tilapia (*Oreochromis Niloticus L.*) Production”** The purpose of the study is to make possible recommendations on the adoption of BSFL meal in fish farming.

I wish to request you to kindly assist in providing the required information, by filling the questionnaire provided, as your views are considered important to this study. The questionnaire has been designed as a series of statements where your views can be shown by putting a tick in the appropriate box. The intention of this study is research and not for any other purpose. You are assured that your response will be treated with the utmost confidentiality.

Kindly answer the questions as candidly as you can.

Thank you.

Kevin Okoth Ouko

PhD Student Researcher

APPENDIX 2: INFORMED CONSENT FORM

Name of Principal Investigator: **KEVIN OKOTH OUKO**

Name of Organization: **JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY**

Name of Project: **SOCIO-ECONOMIC EFFICIENCY OF BLACK SOLDIER FLY LARVAE (*Hermetia illucens* L) MEAL FOR AQUACULTURE PRODUCTION IN KENYA**

This Informed Consent Form has two parts:

- Information Sheet (to share information about the study with you)
- Certificate of Consent (for signatures if you choose to participate)

You will be given a copy of the full Informed Consent Form

I certify that I have read and thoroughly comprehended the participant information sheet and that Mr. Kevin Okoth Ouko, a postgraduate student at Jaramogi Oginga Odinga University in Kenya, fully and clearly described the nature and aim of this research project to me.

I am aware that every bit of information I give will be kept in the strictest of confidence and used solely for the research project. I commit that throughout the study I will be accessible for all necessary activities and that I will be willing to share information in order to help the study become more accurate. I also acknowledge that, even though the research's findings may be published, my real name will not be used anywhere during or after the study to identify me. I am also fully aware that I have the option to withdraw from the research study whenever I choose, with no consequences or negative effects.

Signature of the participant.....

Date.....

For further information contact: Kevin Okoth Ouko

Tel: 0723966477

Email: kevinkouko@gmail.com

APPENDIX 3: FISH FARMERS QUESTIONNAIRE (CAGE OWNERS/MANAGERS AND FISH POND FARMERS)

Kindly tick where appropriate (√).

Number of questionnaire [.....]

Date.....

Name of Farmer..... Telephone.....

Location of the farmer

County.....

Sub- County.....

Beach.....

A. DEMOGRAPHIC CHARACTERISTICS

QUESTIONS	CODES	RESPONSE
1. Category of Fish Farmer	1=Fish Pond Farmer 2=Cage Farmer	
2. Gender of the respondent	1=Male; 0=Female	
3. Are you the household head	1=Yes; 0=No	
4. Age in years of the respondent	Actual number of years	
5. Marital status	1=Married; 2=Single; 3=Others (specify)	
6. Highest level of education	1= None 2=Primary level 3=Secondary level 4= Tertiary college level 5=University level 6=others(specify)	
7. Number of years of schooling	Actual number of years	
8. How many people are currently living with you	Actual number in numbers	
9. How many years have you been fish farming	Number of years	

B. SOCIO-ECONOMIC CHARACTERISTICS

QUESTIONS	CODES	RESPONSE
10. What is your current occupation?	1=Farming; 2= Off-farm business; 3=salaried 4=others (specify)	
11. What type of business do you operate?	1= Hatchery 2= Grow out	
12. What is your annual gross income?	Annual total income received by the fish farmer, including non-farm income (KSh)	
13. What is your annual farm income?	Amount in KSh	
14. How much do you get from fish income in your annual farm income	% fish income	

C. INSTITUTIONAL CHARACTERISTICS

QUESTIONS	CODES	RESPONSE
15. Do you have access to extension service providers	Yes=1, No=0	
16. Did you attend any extension training	Yes=1, No=0	

in the last production year?		
17. If you attended extension training or received extension services, what were your satisfaction levels with extension?	1= Totally satisfied 0 = Totally dissatisfied	
18. Did you access any credit for your fish farming?	Yes=1, No=0	
19. Are you a member of any farming group or organization?	Yes=1, No=0	

D. FISH PRODUCTION

1. Which culture practice are you engaged in? 1= Intensive [] 2= Extensive [] 3= Semi intensive []
2. How many cages/fishponds do you own?
3. Total size of cages/fishponds
4. How many years have you farmed on current land?years
5. Do you farm tilapia only? 1= Yes [] 0= No [] i.e. If “No” what else do you farm?
6. How many times do you produce the tilapia in a given year?
7. What is your production (yield) per cycle? 1=high production (> 1.5 kg per m²), 0 =otherwise (low)

E. FISH FEED

1. Do you make your own fish feed? 1= Yes [] 2= No []
2. If no then where do you get your feed?
3. How far is your fish farm to the feed seller.....? (Km)
4. If you make your own fish feed, do you use fish meal in farm for local fish feed (1= Yes, and 0 if not)
5. What is the quantity of fish meal in own mixed feed?.....Kg
6. Do you think the existing fish feed is expensive? 1= Yes [] 2= No []
7. Do you know the components of the existing feed? 1= Yes [] 2=No []
8. Which of these factors do you consider when buying commercial fish feeds?
1= Ingredient [] 2= Cost [] 3= brand [] 4= others []

F. FARMERS’ ACCEPTANCE OF BSFL MEAL PRODUCTS IN FISH FARMING

Product Description

This feed, which is based on insects, is created using meal from black soldier fly larvae (BSFL) and other components. The primary source of protein in this feed, as opposed to standard diets, is BSFL meal rather than fishmeal. This is because fishmeal is expensive and has a finite future supply. The larvae of the black soldier fly, which is present in tropical regions, are known as BSFLs. It is simple to raise, feeds on organic waste, and produces biomass that is high in protein and fat while cutting the volume of garbage by up to 50%. The BSFL is grown, collected, dried, and processed to formulate this feed. In order to complete the feed formulation, additional components like fish oil, vitamins, etc. are added.

Please respond to these queries and assertions based on this description and your expertise of insect-based feed, if any.

I. Farmers Awareness

1. Have you fed the tilapia with insect before? 1= Yes [] 0=No []
2. What was the result of the trial? 1= poor [] 2= somewhat good [] 3= Good []
3. Have you heard of insect (Black soldier fly) based feed? 1= Yes [] 2= No []
4. If “yes” How did you get to know? 1= institution/organization [] 2= workshop [] 3= Friends and family [] 4= Media [] 5= other Specify.....

II. TAM Constructs

[Enumerator] Please respond to each of the following questions with your thoughts. Make a distinct and independent decision for each item. Work your way through the set of scales quickly. Don't be concerned or confused by certain details. It's your initial thoughts, or the sentiments you have right away regarding the things you want. Despite the fact that some questions may sound identical, they are actually somewhat different.

Please tick as appropriate, the levels at which you agree with the following statements: **Key: SA =Strongly Disagree, A= Agree, N= Neutral, D= Disagree SD = Strongly Disagree**

a) Perceived Usefulness (PU)

	SA	A	N	D	SD
1. Improve the sustainability of fish production					
2. Improve the societal acceptance of fish farming					
3. Lower the ecological footprint of livestock farming					
4. Allow farmers produce enough fish for the world population					
5. Lower feed price and production cost in fish farming					
6. Decrease the overexploitation of water bodies					
7. Lower our dependence on foreign protein sources					
8. Lower the cost of Fish feed					
9. Lower our dependence on imported feed					
10. Improve organic waste management in the country					

b) Perceived Ease of Use (PEOU)

	SA	A	N	D	SD
1. Use of BSFL feed is a system easy to understand					
2. Use of BSFL is a system that would be easy to implement on my fish farm.					
3. Using BSFL meal would enhance my effectiveness on fish production					
4. Using BSF meal will improve my fish production efficiency					

c) Attitude (ATT)

	SA	A	N	D	SD
1. BSFL provide cheap source of protein in fish farming					

2. BSFL Provide nutrients and minerals					
3. Possibility of rearing BSF guarantees availability					
4. Rearing BSF requires small space and is cost effective					
5. BSF has low feeding costs because it feed on wastes thus cleans environment					
6. Hard to create awareness and promote BSFL meal to people					
7. Long time required to change attitudes of people to consider BSFL meal as feed.					

d) Behavioural Intention to Use (INT)

	SA	A	N	D	SD
1. I intend to use BSFL in my fish farm					
2. I would recommend the adoption of BSFL meal for other fish farmers in my region					
3. I would also adopt BSFL meal if the neighboring farmers adopt					

G. FARMERS WILLINGNESS TO PAY FOR BSFL MEAL PRODUCTS IN FISH FARMING

Based on the product description given above, please answer the following questions

1. Would you be willing to pay for BSFL-based fish feed in your fish farm? a) Yes.... b) No....
2. If “No” what is your reason(s)?
3. How much would you be willing to pay per Kg?

Elicited Bidding Price (Kshs)	Yes	No
1.		
2.		
3.		
4.		

4. What can motivate you to purchase BSFL feeds? Tick as appropriate
5. Motivation for BSFL meal use to improve nutritional quality of Nile tilapia. a) Yes.... b) No....
6. Motivation for BSFL meal use to improve growth performance of Nile tilapia a) Yes.... b) No....
7. Motivation for BSFL meal use to reduce feeding cost of Nile tilapia a) Yes.... b) No....

Thank you.

APPENDIX 4: STAKEHOLDERS’ QUESTIONNAIRE

My name is Kevin Ouko, a PhD student at Africa Centre of Excellence in Sustainable Use of Insects as Food and Feed (INSEFOODS) hosted at Jaramogi Oginga Odinga University of Science and Technology, Kenya. I am currently undertaking my research at Kenya Marine

and Fisheries Research Institute (KMFRI). I am working on my PhD thesis research with the broad aim of evaluating the potential contribution of insect-based feeds (specifically Black Soldier Fly Larvae) in fish production in Kenya. I am currently collecting data from various Aquaculture Researchers/Academia, Fish Feed Processors and Entomologists as part of the stakeholders analysis. As one of the experts, this questionnaire is to assess your opinion about the use of insect-based feeds (Black Soldier Fly Larvae meal) in Fish production. I would like to request you to assist with filling this questionnaire for my data analysis and completion of my thesis report. The results of the study will certainly enrich the existing knowledge base on the topic and build a foundation for future actions to sustainable aquaculture production. All information you provide will be treated anonymously and with highest confidentiality.

You can use the below button or the link to go to the survey

Thank you for your support.

1. a) Please select the profession which best describes your job.

Fish farmer/Fish cage manager	<input type="checkbox"/>
Fisheries Officer	
Research Officer/Scientist	<input type="checkbox"/>
Feed processor	<input type="checkbox"/>
Academia/Lecturer	<input type="checkbox"/>
Others	<input type="checkbox"/>

b) If other professions please, specify

c) How long have you been in the aquaculture/insect value chain industry in years?

2 a) How do you assess the impact of the following potential fish feed problems on fish production in Kenya? (1 = very big problem, 2 = big problem, 3 = minor problem, 4 = no problem, 5 = do not know)

Challenges	Very big problem	Big problem	Minor problem	Not a problem	Don't know
High cost of feeds					
Shortage of ingredients					
Poor feed quality					
Lack of knowledge about feed formulation					
Poor feed processing technologies					
High transport,					

storage and handling costs					
Lack of access to fish feeds					

b) Are there further fish feed problems that are not mentioned above? Which ones?

3 a) Which of the following is the key factors that fish farmers consider when purchasing fish feeds?

1= Ingredient 2= Cost 3= Brand 4= Quality

b) Are fish farmers looking for alternative feeds in fish production? 1= Yes 0= No

c) If yes, why so?

4 a) Have you heard about the use of insect-based feed in Aquaculture in Kenya? 1= Yes 0= No

b) If Yes, which insects are you aware of as being used in aquaculture in Kenya?

2. Common House Fly Larvae (*Musca domestica*)
3. Black Soldier Fly Larvae (*Hermetia illucens*)
4. Larvae of butterflies (*Bematistes macarena*)
5. Yellow mealworm (*Tenebrio molitor*)
6. Lesser mealworm (*Alphitobius diaperinus*)
7. House cricket, (*Acheta domesticus*)
8. Field cricket (*Gryllus assimilis*)
9. Silkworms (*Bombyx mori*)
10. Termites (*Macroterms*)
11. Others (specify)

d) Where did you hear about Black soldier fly based aquafeed?

5 a) What do you think about the idea of producing insects instead of grains such as soybean meal or fishmeal for use in fish feed?

Very dissatisfied	dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

b) Are fish farmer aiming to replace fishmeal from fish feed or to reducing it?

c) To what extent do you agree with the following statements?

	Definitely not	No	Not sure	Yes	Absolutely yes
Feeding of fish using insects is a traditional farming practice	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Using insect-based feeds is an unnatural feeding practice in fish farming.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

d) What is your position on the use of insect meal in feed?

e) Do you think that BSFL meal will be well accepted by the fish farmers in Kenya?

Definitely not	No	Not sure	Yes	Definitely yes
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

6. Perceived Risks and Benefits of Using BSFL in Aquaculture

To what extent do you agree with the following statements?

Statements	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Benefits					
Could allow organic waste to be better valorized					
Could allow sustainability to be improved					
Could allow the production of enough fish to world population					
May reduce the price of feed and animal production					
Can improve society's acceptance of fish production					
Reduction in reliance of fishmeal					
Better fish nutritional value					
Risks					
May cause allergic reactions in humans					
May cause allergic reactions in animals					
Can impact on biodiversity if the BSFL are accidentally released					
May introduce microbiological contamination in food supply chain					
Can increase competitiveness with other agricultural activities					
May reduce the consumers acceptance of food resulting from animal production					
Can introduce chemical residues into the food supply chain					

7. Compared with fish fed on conventional diets such fish meal, fish fed on BSFL meal will have:

Much slower growth rates	Slower growth rates	Neither faster nor slower growth rates	Faster growth rates	Much faster growth rates	Don't know
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Much higher feed conversion ratios (less efficient)	Higher feed conversion ratios (less efficient)	Has neither higher nor lower feed conversion ratios	Lower feed conversion ratios (more efficient)	Much lower feed conversion ratios (more efficient)	Don't know
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

8. To what extent are fish farmers concerned about the following when BSFL are used in aquaculture feed” on a five-point interval scale

Perception concern statements	Not all	Rather not	Neither nor	Rather	Very much
Price of insect-based feed					
Processing of insect-based feeds					
Labelling of the end product					
Guarantee of sufficient insect supply					
Quality of insect-based feeds					
Traceability					
Sanitary policy and monitoring					
Communication with the aquaculture farmers					
Legislation					
Attitude of the feed suppliers					
Applying good agriculture/aquaculture management practices					
How BSFL are reared (rearing substrates)					

10 a) If the procedures were put in place to ensure the safety of BSFL as fish feed would you support the legalization of its use in Kenya?

Definitely not	No	Not sure	Yes	Definitely yes
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

b) When considering the legalization of BSFL meal, how much importance do you think should be placed on the following considerations?

	Not at all important	Not important	Neither important nor unimportant	Important	Very important
Feed safety	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sanitary policy and inspection	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Traceability	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Profitability	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Meat quality	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Communication with fish farmers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Environmental impacts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Labelling of the end product	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fish farmers acceptance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Feed prices	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Efficient use of resources	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Perception of the fish industry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

c) If the use of BSFL were legalized, and procedures were put in place to ensure its feed safety, would you consider advocating for the use of BSFL by fish farmers?

Definitely not	No	Might or might not	Yes	Definitely yes
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11. What are your expectations from the BSFL producers/farmers and feed traders?

1. They reduce their price
2. Increase production
3. Increase product quality

12. What is your opinion about the possible driving factors to promote the adoption of BSFL in fish farming?

Statement	Disagree	Neutral	Agree
Creating and enhancing fish farmers awareness of the benefits of BSFL in fish production			
Training farmers on mass rearing of BSFL			
Development of BSFL certification and updating of standards			
Identifying pioneer farmers of safe BSFL production and their introduction as the leading farmers			
Identification of appropriate substrates for BSFL rearing			
Reasonable pricing of BSFL based feeds to motivate producers and fish farmers			
Orienting aquaculture feed research towards insect-based feeds production-based studies			






13. What is your gender?

Male	<input type="checkbox"/>
Female	<input type="checkbox"/>

14. What is your age bracket?

0-18	<input type="checkbox"/>
19-30	<input type="checkbox"/>
31-50	<input type="checkbox"/>
51+	<input type="checkbox"/>

APPENDIX 5: NACOSTI RESEARCH PERMIT

 REPUBLIC OF KENYA	 NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION
Ref No: 737018	Date of Issue: 02/December/2020
RESEARCH LICENSE	
	
This is to Certify that Mr.. Kevin Okoth Ouko of Jaramogi Oginga Odinga University of Science and Technology, has been licensed to conduct research in Homabay, Kisumu, Siaya on the topic: Socio-economic Efficiency of Black Soldier Fly Larvae (Hermetia illucens) as an Alternative Feed in Nile Tilapia (Oreochromis niloticus L.) Production for the period ending : 02/December/2021.	
License No: NACOSTI/P/20/8040	
Applicant Identification Number 737018	 Director General NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION
	Verification QR Code 
NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.	

APPENDIX 6: JOOUST BPS RESEARCH AUTHORIZATION



JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE & TECHNOLOGY
BOARD OF POSTGRADUATE STUDIES
Office of the Director

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

P.O. BOX 210 - 40601
BONDO

Our Ref: A461/4082/2019

Date: 17th September 2020

TO WHOM IT MAY CONCERN

RE: KEVIN OKOTH OUKO - A461/4082/2019

The above person is a bonafide postgraduate student of Jaramogi Oginga Odinga University of Science and Technology in the School of Agricultural and Food Sciences pursuing a PhD in Food Security and Sustainable Agriculture. He has been authorized by the University to undertake research on the topic: "Socio-Economic Efficiency of Black Soldier Fly Larvae (*Hermetia illucens*) Meal as an Alternative Feed in Nile Tilapia (*Oreochromis niloticus* L.) Production."

Any assistance accorded him shall be appreciated.

Thank you.

Prof. Dennis Ochieng'ho

DIRECTOR, BOARD OF POSTGRADUATE STUDIES

APPENDIX 7: JOOUST ETHICS REVIEW APPROVAL



**JARAMOGI OGINGA ODINGA
UNIVERSITY OF SCIENCE AND TECHNOLOGY
DIVISION OF RESEARCH, INNOVATION AND OUTREACH
JOOUST-ETHICS REVIEW OFFICE**

Tel. 057-2501804

Email: erc@jooust.ac.ke

Website: www.jooust.ac.ke

P.O. BOX 210 - 40601

BONDO

OUR REF: JOOUST/DVC-RIO/ERC/E2

28th October, 2020

Kevin Okoth Ouko

SAFS

JOOUST

Dear Mr. Ouko,

RE: APPROVAL TO CONDUCT RESEARCH TITLED "SOCIO-ECONOMIC EFFICIENCY OF BLACK SOLDIER FLY LARVAE (OREOCHROMIS NILOTICUS L) PRODUCTION"

This is to inform you that JOOUST ERC has reviewed and approved your above research proposal. Your application approval number is **ERC/28/10/20-12**. The approval period is from 28th October, 2020 – 27th October, 2021.

This approval is subject to compliance with the following requirements:

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

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

Yours sincerely,

Prof. Francis Anga wa
Chairman, JOOUST ERC

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

APPENDIX 8: TEST OF NORMALITY

Tests of Normality

	Treatment	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Measurement	0% BSFL, 100% FM	.187	33	.005	.855	33	.000
	25% BSFL, 75% FM	.198	33	.002	.854	33	.000
	50% BSFL, 55% FM	.199	3	.002	.841	33	.000
	75% BSFL, 25% FM	.205	33	.001	.832	33	.000

a. Lilliefors Significance Correction

Test for homogeneity of Variance

Levene's Test of Equality of Error Variances

Dependent Variable: Measurement

F	df1	df2	Sig.
3.506	43	88	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Treatment + Week

Tests of Between-Subjects Effects

Dependent Variable: Measurement

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6248.716 ^a	13	480.670	481.029	.000
Intercept	6520.582	1	6520.582	6525.439	.000
Treatment	17.964	3	5.988	5.992	.001
Week	6230.753	10	623.075	623.539	.000
Error	117.912	118	.999		
Total	12887.211	132			
Corrected Total	6366.629	131			

a. R Squared = .981 (Adjusted R Squared = .979)

From the output, F= 5.992 with 3 and 10 as degrees of freedom

	(I) Treatment	(J) Treatment	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Tukey HSD		25% BSFL, 75% FM	.24609	.007	.1704	1.4530
	0% BSFL, 100% FM	50% BSFL, 55% FM	.24609	.915	-.8019	.4808
		75% BSFL, 25% FM	.24609	.729	-.3865	.8961
		0% BSFL, 100% FM	.24609	.007	-1.4530	-.1704
	25% BSFL, 75% FM	50% BSFL, 55% FM	.24609	.001	-1.6136	-.3309
		75% BSFL, 25% FM	.24609	.113	-1.1982	.0844
		0% BSFL, 100% FM	.24609	.915	-.4808	.8019
	50% BSFL, 55% FM	25% BSFL, 75% FM	.24609	.001	.3309	1.6136
		75% BSFL, 25% FM	.24609	.335	-.2260	1.0566
		0% BSFL, 100% FM	.24609	.729	-.8961	.3865
	75% BSFL, 25% FM	25% BSFL, 75% FM	.24609	.113	-.0844	1.1982
		50% BSFL, 55% FM	.24609	.335	-1.0566	.2260

APPENDIX 9: TABLE A1 LATENT VARIABLES AND INDICATOR ID

Table A1: Latent variables, Indicator ID and the corresponding questionnaire statements used within the survey

Latent Variable	Indicator	Item Measure	References	Mean	SD
Perceived Usefulness	PU1	Improve the sustainability of fish production	Chia <i>et al.</i> , 2019	3.70	1.000
	PU2	Improve the societal acceptance in fish farming	Verbeke <i>et al.</i> , 2015	3.05	1.216
	PU3	Lower the ecological footprint of livestock farming	Chaalala <i>et al.</i> , 2018	1.87	.884
	PU4	Allow farmers produce high quantities of fish for the world population	Verbeke <i>et al.</i> , 2015	2.21	.893
	PU5	Lower production cost in fish farming without fish reducing quality	Sinansari & Fahmi, 2020	1.39	.587
	PU6	Decrease the overexploitation of water bodies	Tiu, 2012	1.87	1.079
	PU7	Lower our dependence on foreign protein sources	Verbeke <i>et al.</i> , 2015	1.68	.827
	PU8	Lower the cost of Fish feed	Verbeke <i>et al.</i> , 2015	1.33	.555
	PU9	Lower our dependence on imported feed	Verbeke <i>et al.</i> , 2015	1.52	.764
	PU10	Improve organic waste management in the country	Dicke, 2018	1.36	.619
Perceive Ease of Use	PEOU1	Use of BSFL feed is a system easy to understand	Oppong, 2017	1.78	1.105
	PEOU2	Use of BSFL is a system that would be easy to implement on my fish farm.	Rana <i>et al.</i> , 2015	2.00	1.229
	PEOU3	Using BSFL meal would enhance my effectiveness on fish production	Mulumpwa, 2018	2.34	1.271
	PEOU4	Using BSF meal will improve my fish production efficiency	Roffeis <i>et al.</i> , 2018	2.19	1.208
Attitude	ATT1	BSFL provide cheap source of protein in fish farming	Higa <i>et al.</i> , 2020	1.35	.517
	ATT2	BSFL Provide nutrients and minerals	Makkar <i>et al.</i> , 2014	1.96	.930
	ATT3	Possibility of rearing BSF guarantees availability	Yildirim-Aksoy <i>et al.</i> , 2020)	2.21	1.255
	ATT4	Rearing BSF requires small space and is cost effective	van Huis, 2013	1.36	.726

	ATT5	BSF has low feeding costs because it feed on wastes thus cleans environment	Dicke,2018	1.32	.552
	ATT6	Hard to create awareness and promote BSFL meal to people based on legislative issues	Belghit <i>et al.</i> , 2019	3.27	1.157
	ATT7	Long time required to change attitudes of people to consider BSFL meal as feed.	Kelemu <i>et al.</i> , 2015	2.99	1.123
Behavioral Intention	INT1	I intend to use BSFL in my fish farm	Ssepuyya <i>et al.</i> , 2019	1.83	1.229
	INT2	I would recommend the adoption of BSFL meal for other fish farmers in my region	Domingues <i>et al.</i> , 2020	1.68	1.238
	INT3	I would also adopt BSFL meal if the neighboring farmers adopt	Joffre <i>et al.</i> , 2020	1.59	1.132

APPENDIX 10: LIST OF MANUSCRIPTS AND CONFERENCE ATTENDANCE

MANUSCRIPTS PUBLISHED

1. **Ouko K.O**, Mukhebi A.W, Obiero K.O, Opondo F.O (2022). Understanding Fish Farmers Intention to Accept Black Soldier Fly Larvae in Nile Tilapia Production. *All life-Taylor and Francis journal*. <https://doi.org/10.1080/26895293.2022.2112765>)
2. **Ouko KO**, Mukhebi AW, Obiero KO, Opondo FA, Ng'ong'a CA, and Ongor DO (2022). Stakeholders' perspectives on the use of black soldier fly larvae as an alternative sustainable feed ingredient in aquaculture, Kenya. *African Journal of Agricultural and Resource Economics*. Volume 17, Number 1 (2022), pp 64–79. [https://doi.org/10.53936/afjare.2022.17\(1\).4](https://doi.org/10.53936/afjare.2022.17(1).4)
3. **Ouko KO**, J, B Mboya, K O Obiero, E O. Ogello, AW Mukhebi, M Muthoka, J M Munguti (2023) Determinants of fish farmers' awareness of insect-based aquafeeds in Kenya; The case of Black Soldier Fly Larvae Meal *Cogent Food and Agriculture - Taylor and Francis*. <https://doi.org/10.1080/23311932.2023.2187185>

MANUSCRIPTS UNDER REVIEW

4. **Ouko. K. O.**, Obiero K. O. and Mukhebi A. W. (2022). Effects of Partial Substitution of Fish Meal with Black Soldier Fly Larvae Meal on Growth Performance and Economic Efficiency in Diets of Nile Tilapia (*Manuscript Submitted-Fundamental and Applied Agriculture*)

CONFERENCES ATTENDED

1. Participated as a presenter at the Future Africa's Early Career Research Leader Fellowship (ECRLF) program workshop held at Laikipia University, Nyahururu on 6th -8th July 2021, under sub-theme: Sustainable Value Chain Agriculture Transformation Approaches.

Topic: Potential Utilization of Insects as Alternative Protein Source in Diets of Farmed Fish: Acceptance of Black Soldier Fly (*Hermetia illucens*) Larvae Meal in Kenya.

https://www.futureafrica.science/images/content/whats_happening/2021/july/ECRLF/LU%20ECRLF%20CONFERENCE%20PROGRAMME.pdf