PERCEPTION OF SMALLHOLDER CHICKEN FARMERS ON BLACK SOLDIER FLY LARVAE AS AN ALTERNATIVE PROTEIN SOURCE IN UASIN GISHU COUNTY, KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Science Degree in Agribusiness Management of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

This Thesis is my original work and to the best of my knowledge, has not, wholly or in part, been submitted for an award of any certificate in any other institution.

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Recommendation

This Thesis was developed with our guidance and approval as University supervisors.

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DEDICATION

This thesis is dedicated to my late parents, my husband, my sons Trevor and Brighton, and my siblings Bonface, Evans, Sylvia, Mercy, Leeroy and Vera.

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ABSTRACT

Owing to rapid population growth, food poverty in Uasin Gishu County stands at 32% as of 2023; that has resulted in an increase in demand for animal-based protein particularly chicken products whose production heavily depends on conventional protein sources. The available conventional proteins are insufficient, unsustainable and expensive for the less resource-endowed locals. The scarcity of conventional protein ingredients has driven for the search of alternative protein sources for animal feed. Black soldier fly larvae (BSFL) has been identified as an alternative protein source and its incorporation in livestock feed is gaining popularity worldwide. However, information regarding smallholder chicken farmers perception of BSFL-Based feed, its competitiveness and incorporation in Livestock feed is still scanty in Uasin Gishu County. The aim of this study, therefore, was to contribute to food security and competitiveness of BSFL through its enhanced utilization as an alternative, affordable and reliable source of protein for the livestock feeding industry in Uasin Gishu County. Specifically, it sought to: analyse smallholder chicken farmers' perception of BSFL-based feed, to determine the factors influencing the adoption of BSFL-based feed and finally to determine the costs and benefits of using BSFL compared to conventional protein in Uasin Gishu County. The study was based on data collected from a sample of 245 smallholder chicken farmers. Multistage sampling procedure was used to select the respondents using semi-structured questionnaires. Principal component analysis was used to analyse chicken farmers' perception of BSFL-Based feed, Binary probit regression model was employed to determine factors influencing the adoption of BSFL-Based feed, and Gross margin analysis was used to determine the costs and benefits associated with BSFL. The results indicate that chicken farmers' perception was positive with regard to the overall perception index, social acceptability, marketability and performance of BSFL. The results revealed that adoption of BSFL was at (38%). Findings revealed that age was statistically significant at 5%, education level (5%), monthly income (1%), participation in off farm activities (1%), awareness of BSFL attributes (1%), contact with agricultural extension officers (10%), and amount of credit borrowed (1%) significantly influenced the likelihood to utilise BSFL. The results suggest that farmers adopting insect-based feed realised more profits as opposed to non-adopters. Finally, interventions like trainings and farm demonstrations that increase farmers' technical know-how on improving the productivity of chicken reared on BSFL are essential in reducing chicken farmers' uncertainties of accepting BSFL and encouraging its uptake.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASALS	Arid and Semi-arid Lands
BSFL	Black Soldier Fly Larvae
CAC	Codex Alimentarius Commission
CBA	Cost-Benefit Analysis
CIDP	County Integrated Development Plan
CP	Crude Protein
DOI	Diffusion of Innovation
DPH	Department of Public Health
DVS	Department of Veterinary Services
FAO	Food and Agriculture Organization of the United Nations
GAIN	Global Agricultural Information Network
GAPs	Good Agricultural Practises
GDP	Gross Domestic product
GM	Gross Margin
GMA	Gross Margin Analysis
GoK	Government of Kenya
HCDA	Horticultural Crops Development Authority
HF	House Fly
ICIPE	International Centre of Insect Physiology and Ecology
IPIFF	International Platform of Insect for Food and Feed
ISO	Organization for Standardization
KALRO	Kenya Agricultural and Livestock Research Organization
KDB	Kenya Dairy Board
KEPHIS	Kenya Plant Health Inspectorate Services
KNBS	Kenya National Bureau of Statistics
KCSAP	Kenya Climate-smart Agriculture Project

MLE	Maximum Likelihood Estimation
NFNSP	National Food and Nutritional Security Policy
NLP	National Livestock Policy
OLS	Ordinary Least Squares
PCA	Principal Component Analysis
SD	Standard Deviation
SE	Standard Error
SDG	Sustainable Development Goals
SPS	Sanitary and Phytosanitary Standards
SSA	Sub-Saharan Africa
TBT	Technical Barrier to Trade agreements
TPB	Theory of Planned Behaviour
TR	Total Revenue
TVC	Total Variable Cost
UG	Uasin Gishu
UTAUT	Unified Theory of Acceptance and Use of Technology
VIF	Variance Inflation Factor
WTO	World Trade Organization

CHAPTER ONE

INTRODUCTION

1.1 Background Information

One strategy for enhancing food production and reducing poverty in Africa is to intensify agricultural production in order to boost the competitiveness and profitability of livestock enterprises (Food and Agriculture Organization of the United Nations [FAO], 2017). The livestock sector in Africa accounts for one-third of the global livestock population (Au-Ibar, 2016) and approximately 40% of African agricultural GDP, ranging from 12% to 78% in individual countries (Pawlak & Kołodziejczak, 2020). Poultry, fish, and pig production are the fastest-growing agricultural ventures in Sub-Saharan Africa (SSA), providing income and employment opportunities.

The livestock sector plays a major role in the Kenyan food system, contributing approximately 12 percent of the country's overall GDP and 40 percent of agricultural GDP, and employs about half of the agricultural labor force (Kenya Markets Trust 2019). The domestic livestock also meets local demands for meat, milk, dairy products, eggs, and other livestock products accounting for approximately 30% of total marketed agricultural products (Government of Kenya [GoK], 2019).

The livestock industry in Kenya is projected to grow significantly over the next five to ten years, supporting the nation's food security as the population quickly increases from 47 million to 96 million people by 2035 (Kenya National Bureau of Statistics [KNBS], 2018). Due to its low capital and space requirements, poultry keeping is one of Kenya's most popular livestock enterprises. It contributes approximately 55% of the GDP of the livestock sector and 30% of the GDP of agriculture, or 7.8% of Kenya's GDP, and employs approximately two million people directly in production and marketing as well as indirectly through linkages and input suppliers such as feeds, vaccines and veterinary services among others.

With the country's population expected to double to 96 million in 10 years, with nearly half of the people living in urban areas, up from 27 percent today, GDP *per capita* is expected to increase by more than 140 percent by 2050, (FAO, 2017). In Kenya, 66% of households own at least one type of livestock, with 98% of rural households owning poultry. Through the provision of eggs, meat, and manure, Kenya's poultry sub-sector can increase household income and contribute to food and nutrition security (Omiti & Okuthe, 2009; Omondi, 2022). However, the sector's potential is hampered by the high cost of production, with feed alone accounting for more than 65%-70% of total production costs. The poultry sector is practiced on a small to medium scale and is a fast-growing industry in Kenya, with increased demand for poultry products driving up production. In Kenya, approximately 90% of smallholder farmers raise chicken, either indigenous chicken or exotic chicken breeds (Ssepuuya *et al*., 2017).

Feed production is constrained by food-feed competition, limited availability of land, fertilizers, energy, and water. The imbalance between demand and supply, in turn, increases the prices of inputs and poultry products (Makkar *et al*., 2014; Van Huis *et al*., 2013). Over the last 5-7 years, the global prices of fishmeal, maize, and soya bean meal increased by 70%, 65%, and 94%, respectively (World Bank, 2018). Collectively, these issues represent challenges to livestock production, human beings, and the environment. Demand for animal feed-grade fish and fishmeal greatly exceeds supply. Livestock production is the most prioritized value chain in the county; chicken value chain comes second after dairy value chain (Uasin Gishu County integrated development plan (CIDP 2019) which is a factor that motivates the undertaking of the study in Uasin Gishu County. A shift to an insect-based feed offers circular economy opportunities and thus enhances environmental clean-up services by recycling bio-waste and reduction of greenhouse gas emissions (Ermolaev *et al*., 2019; Mertenat *et al*., 2019).

In Uasin Gishu County, most farmers practice chicken farming on a small-scale capacity, the number of chicken farmers in Kipsomba ward, Soy sub-county are 2612, while chicken farmers in Tulwet-Chuiyat ward in Kesses sub-county are 1840, and 1129 chicken farmers in Kapsoya, Ainabkoi Sub-county (CIDP 2018). More so, the county is boosting knowledge and reaching out to chicken farmers through projects such as '*Inua Mama na Kuku'* and Kenya climate-smart agriculture funded by the World Bank which has increased the population of chicken posing a challenge to the farmers on how to feed them with quality feed, in addition to its county integrated development plans on poverty alleviation, food security, and economic growth (CIDP, 2018). In poultry production industry, feed is the most important input, accounting for 65%-70% of the total production cost (Ssepuuya *et al*., 2017). High feed cost in poultry production is the major challenge faced by international as well as local industries due to competition for feed materials shared by animals and humans, thus resulting in low-quality raw materials mainly used in poultry feed production.

Also, there has been a shift in human diets associated with economic and social changes; the increased consumption of animal products is likely to continue in the coming 5 years. In Kenya, fishmeal is the most preferred protein source for poultry feed production (Yin *et al*., 2011). On the other hand, the use of insects in animal feeds has been less researched and they exhibit great potential for development as a standard ingredient in animal feed. Initiatives on awareness creation to boost adoption of BSFL-Based feed has been promoted by Kenya Agricultural Livestock and Research Organization (KALRO) (Chia, 2019).With growing interest by the private and public sectors in partnering with the International Centre of Insect Physiology and Ecology (ICIPE) to explore the use of insects for poultry feed. BSFL has been identified for mass rearing due to its ability to convert organic waste into high-quality crude protein (CP), fat, amino acids, fatty acids, vitamins, and minerals that are comparable or superior to that of fishmeal and soybean (Onsongo, 2017; Onsongo *et al*., 2018;Ssepuuya *et al*., 2017).

Although studies have shown that the consumers of eggs from laying chicken fed on Commercial black soldier fly larvae meal had positive perception and are willing to pay for such products because the eggs had satisfying taste and aroma (Khaemba *et al*., 2021) there is still limited research on the competitiveness of black soldier fly larvae as an alternative protein source for chicken coupled with limited published literature on farmers' perception of insect-based feeds. Therefore, understanding farmers' perceptions will provide an accurate reflection of their contextual situation, which could impede the uptake of innovations (Fatch *et al*., 2020). Traditionally, insects are associated with disgust (Sogari *et al*., 2019), and dirt and are considered to be pests, hence the belief that they should be eliminated from the food supply chain (Nyangena *et al*., 2020). Thus, understanding farmers' perceptions of black soldier fly-based feeds is an important starting point in initiatives that seek to improve livestock welfare through conscious feeding practices and effective management of their health (Otieno & Ogutu, 2019). This study sought to analyse smallholder chicken farmers' perception of BSFL-based feed and socioeconomic factors influencing the conceived perceptions among smallholder chicken farmers in Ainabkoi, Soy and Kesses sub-counties in Uasin Gishu County

1.2 Statement of the Problem

Fishmeal is a common source of protein whose use competes with human food. Due to its limited availability, the cost of these feed ingredient has rapidly increased making it expensive for smallholder chicken farmers who rely on local supply of fishmeal as a protein ingredient for own farm feed formulation, this therefore affects the smallholder farmers' profitability. Kenya produces limited fishmeal which translates to reliance on expensive imported feeds. Fishmeal is becoming a less reliable protein source due to food-feed competition, overfishing, pollution, and water hyacinth invasion. Increased demand for fishmeal has motivated the search for alternative sources of protein incorporation in animal feeds. In recent years, there has been growing interest to incorporate Black soldier fly larvae as an alternative source of protein to fishmeal in chicken feed for improved nutrition, sustainability, and animal welfare benefits. BSFL-based feeds have been shown to increase egg production, satisfactory taste and attaining chicken live weight cost-effectively. The BSFL are perfect converters of organic waste to organic manure and valuable biomass which consists of 40% protein and 30% fat. Initiatives on awareness creation to boost adoption have been promoted by Kenya Agricultural Livestock and Research Organization as well as Kenya climate-smart agriculture although the rate of adoption is still low. Furthermore, the perception of smallholder chicken farmers towards the use of BSFL-based feed has received limited research. This study sought to fill the knowledge gap by assessing smallholder chicken farmers' perception of BSFL-based feed as an alternative protein source and socioeconomic factors influencing the conceived perceptions in Ainabkoi, Soy and Kesses Sub-counties, in Uasin Gishu County, Kenya.

1.3 Objectives

1.3.1 General Objectives

To contribute to food security and competitiveness of black soldier fly larvae through its enhanced utilization and incorporation as an alternative, affordable and reliable source of protein for the livestock feeding industry in Uasin Gishu County.

1.3.2 Specific Objectives

i. To analyse smallholder chicken farmers' perceptions of BSFL-based feed in Ainabkoi, Soy and Kesses sub-counties in Uasin Gishu County.

ii. To determine the factors influencing the adoption of BSFL-based feed among smallholder chicken farmers in Ainabkoi, Soy and Kesses Sub-counties in Uasin Gishu County.

iii. To determine the costs and benefits of using BSFL compared to conventional protein sources in Ainabkoi, Soy and Kesses sub-counties in Uasin Gishu County.

1.4 Research Questions

i. What are smallholder chicken farmers' perceptions toward BSFL-based feed in Ainabkoi, Soy and Kesses sub-counties in Uasin Gishu County?

ii. What are the factors influencing the use of BSFL as an alternative protein source among smallholder chicken farmers in Ainabkoi, Soy and Kesses Sub-counties in Uasin Gishu County?

iii. What are the costs and benefits of using BSFL as compared to conventional protein sources in Ainabkoi, Soy and Kesses sub-counties in Uasin Gishu County?

1.5 Justification of the Study

The food poverty rate in Uasin Gishu County stands at 32 percent, due to overdependence on rain fed agriculture that has been adversely affected by climate change. Among the development strategies put forward to address the problem are: food crop diversification, on-farm value addition and intensive small livestock commercialization projects to enhance food security and increase farmers' incomes in the county. The findings of this study contribute to the attainment of the county's integrated development plan (CIDP) on food security (goal number 1) and improving the nutritional status and reducing poverty and increasing income among its residents (goal number 2). Chicken farming is anchored to National poultry policy (NPP) on enhancing improvement of rural livelihood and increased contribution to economic development. The findings of the study also contribute to achievement of National livestock policy (NLP) (2019) that identifies poultry and poultry products as an important source of food security and wealth creation with the aim of utilizing livestock resources for food and nutrition security and improved livelihood while safeguarding the environment.

The study also contributes to the dried insect meal for compounding animal feed policy which allows the inclusion of insect in animal feed and guides its application, which was approved in March 2017 in Kenya and Code of practice (KEBS, 2020) on production and handling of insects for feed and food that ensures safe use of insects for food, feed and nutrition security. The Code of practice makes reference to the International Platform of Insects for Food and Feed (IPIFF) policy on incorporation of insects in livestock feeds. On the other hand, chicken farming is in line with the achievement of National Food and Nutritional Security Policy (NFNSP) which helps in increasing the quantity and quality of food available that is affordable to consumers. The findings also contribute to the attainment of big 4 agenda on food security.

It also contribute to the attainment of sustainable development goals (SDGs) (number one) on poverty reduction, innovative nation (number 9), zero hunger (number 2) and sustainable communities (number 11) by the communities embracing the uptake of BSFL farming to utilize market waste and supply the insects to livestock farmers. Lastly, it makes a contribution to the body of knowledge and literature to inform policymakers on sustainable and profitable poultry farming in the county and the nation at large on interventions geared towards increasing uptake BSFL among poultry value chain actors, and also the results would be used for further research about BSFL.

1.6 Scope and Limitations

The conventional protein source considered in this study is fishmeal since it is an animal-based protein similar to black soldier fly larvae with comparable benefits to chicken. The survey was conducted in Ainabkoi, Soy and Kesses Sub-Counties in Uasin Gishu County, involving smallholder chicken farmers who buy ingredients including BSFL and fishmeal to formulate their own feeds for their chicken. The farmers producing black soldier fly larvae in Uasin Gishu County were beneficiaries of Kenya climate smart agriculture project who did not incur all the production cost since they were beneficiaries of grants to cover the initial production costs, which translated to lower prices for black soldier fly larvae as compared to the current market prices for black soldier fly larvae. The finding of the study was limited to the responses that were obtained from the farmers who were interviewed. The quality of responses depended on the integrity, faithfulness, and consistency of the respondents and the research assistants.

1.7 Operational Definition of Terms

Acceptability: Uptake and use of new innovations and technologies that are guided by the beliefs and social dynamics of the community in the livestock feed industry.

Adopters: Smallholder chicken farmers who are incorporating black soldier fly larvae when formulating their own feeds.

Adoption: using black soldier fly larvae based feed as a protein alternative by smallholder chicken farmers in Uasin Gishu County

Black soldier fly larvae users: Smallholder chicken farmers incorporating black soldier fly larvae as an alternative protein source.

Black Soldier Fly Larvae-based Feed: Chicken feed that incorporates black soldier flies larvae as a protein source to replace the conventional protein sources such as fishmeal.

Conventional protein sources: Utilization of protein sources such as soybean, fishmeal, canola and sunflower as a feed ingredient by smallholder chicken farmers who formulate own feeds at farm level in Uasin Gishu County.

Marketability: Cautiousness of how consumers of eggs and chicken meat may perceive changes to chicken diets such as use of black soldier fly larvae as an alternative protein source.

Non-adopters: Smallholder chicken farmers who are not utilising black soldier fly larvae, but are incorporating fishmeal as a protein source when formulating their own chicken feeds.

Perception: smallholder chicken farmer's knowledge and understanding of the comparative characteristics of BSFL-based feed as a protein in chicken feeds over conventional sources such as fishmeal protein sources.

Performance: The nutritional composition of the chicken feed and notable indicators that farmers can monitor in their chicken flock.

Smallholder Chicken Farmer: a farmers rearing chicken between 20 and 200 either for commercial purpose or own consumption.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter gives literature reviewed on previous related studies. The literature is presented as follows; Overview of black soldier fly farming in Kenya, Overview of Insects incorporation as livestock feed in Kenya, Overview of Insects incorporation as human food in Kenya, current policies on incorporation of insects as feed in Kenya, Chicken production system in Kenya, Chicken farmers' perception of BSFL-based products, determinants of Farmer's Adoption of Insect-Based Feed, costs and associated benefits, and finally the theoretical framework and conceptual framework of the study.

2.2 An Overview of Black Soldier Fly in Kenya

The black soldier fly, *Hermetia illucens*, is a true fly (Diptera) of the family Stratiomyidae. Though originally native to the Americas, it now occurs worldwide in tropical and temperate regions (Anankware *et al*., 2015; Van Huis *et al*., 2013). It is a tropical fly that was first seen in 1930 in the Islands. It is said to have moved from Argentina to Boston and Seattle and later spread to Europe, India, Asia, and Australia during World War II. Lack of hardiness to the cold precludes its invasion of non-native regions such as Northern Europe. Black soldier fly larvae can occur in a very dense population of organic wastes such as coffee bean pulp, vegetables, distillers' waste, and fish offal (fish processing by-products). It is mostly considered a good feed protein ingredient because of its ability like other insect species to convert large amounts of organic waste (above 1 billion tons every year) into protein-rich biomass with an excellent amino acid profile (Leverenz *et al*., 2019; Onsongo *et al*., 2018). These insects are often found around decaying organic matter for example animal manure or plant material. Insects contain high levels of protein and their production has a small ecological footprint (Van Huis, 2013). According to Biasato *et al*. (2019), insect-based feed can be an excellent replacement for fishmeal or soybean meal in poultry feed.

The replacement of 50% of a dietary fish meal with maggot meal in a chicken's diet revealed that BSFL-Based feed was superior to the fish meal based diet in both performance and economics of production (Okah & Onwujiariri, 2012). Among the insect species that are mass-reared, the black soldier fly (BSF) *Hermetia illucens*, house fly (HF) *Musca domestica*, and yellow mealworm *Tenebrio Molitor* have received considerable attention because they can feed on different substrates including organic waste streams (Chia *et al*., 2019). The ability of these insects to convert organic waste into high-quality nutrients has rapidly opened innovative economic prospects. These include insect-based protein as an alternative to fishmeal or soybean meal for pigs (Biasato *et al*., 2019), poultry (Onsongo *et al*., 2018) and fish (Iaconisi *et al*., 2017). BSF and HF larvae are currently reared exclusively as feed ingredients (Van der Fels-Klerx *et al*., 2018; Van Huis *et al*., 2013).

According to Nadeau *et al*.(2015), thousands of insect species are consumed worldwide all but a dozen or so are wild caught by more traditional societies and cannot at this time be farmed, with consequences for regular supply and for conservation (Lima *et al*., 2009).The species commonly sold and consumed in the West ,statistics show that less than 1% of the insects are consumed in Africa, such as house crickets and mealworms, are thus not necessarily the most sustainable species nor those with the most desirable properties such as taste and texture.

2.2.1. The Life Cycle of Black Soldier Fly Larvae

The BSF develops through five developmental stages including egg, larval, pre-pupae, pupae, and adult stages. The BSF larval phase is divided into six stages. During the larval period, fat reserves are accumulated to meet the nutritional requirements of adult flies (Myers *et al*., 2008) the development time from egg to adult typically ranges between 40-43 days (Li *et al*., 2011). The female BSF deposits about 500-1000 eggs in cracks and crevices near or in the decaying matter (Diclaro & Kaufman, 2009). The larvae hatch in 3-4 days. They feed on organic matter and in about 14 days, they develop into pre-pupae. The pre-pupae disperse from the feeding substrate to sites that are suitable for pupation.

The exoskeleton darkens and a pupa develops, from which an adult fly encloses within approximately 14 days. Approximately two days after adult emergence, the male and female flies are ready to mate (Gerhardt & Hribar, 2019). The larvae contain 40% crude protein content and 30% fat content (St-Hilarie *et al*., 2007). A study conducted on channel catfish showed that replacing *Menhaden* with BSF larvae do not result in loss of growth. However, the price of FM is constantly on the rise each day, for instance, *Menhaden*, containing 57-65% protein is valued at about Kes 160 per kg in major Kenyan commodity markets. Black soldier fly larvae projected value is Kes 105 per kg (Bullock *et al*., 2013).

2.2.2. Associated Benefits of Black Soldier Fly Larvae

BSFL are voracious feeders and can reduce waste by up to 50%. This is known as the bioconversion technology of BSFL. Since the 1990s, BSFL has been suggested as a way to dispose of organic waste by allowing BSFL to feed on it, converting it into biomass and the resultant waste used as fertilizer (Diener *et al*., 2011; Van Huis *et al*., 2013) Farmers may use on-farm waste streams such as crop leftovers as input for BSF production and add the resulting fly larvae to the feed for their chicken. This results in a circular approach that closes the nutrient cycles on farms. With limited space, resource-poor farmers that engage in insect farming may increase their productivity while contributing to waste management (Pomalégni *et al*., 2017). Smallholder farmers can start up innovative businesses with limited inputs to generate insect meals for animal feed and the waste stream of insect production can be used as organic fertilizer for crop production (Chaalala *et al*., 2018). Lack of access to affordable protein sources for farmed pigs, chickens, and fish in Kenya can deter farmers from starting a small livestock venture, with less likelihood to have access to the required capital. Traditionally, Kenyan farmers use fishmeal and soybean as protein sources for their animals, but both can be problematic for smallholder communities because Kenya does not produce high quantities of soybean, and limited local supply translates to expensive import taxes, which often push the commodity out of the reach of smallholder operations.

Likewise, fishmeal is becoming a less reliable protein source due to greater market competition, overfishing, and traders often adulterating supplies with soil to increase profit margins (Beesigamukama *et al*., 2020). Replacing black soldier fly larvae based feed with soybean and fishmeal in proportions of 10 to 56%, broiler quails and chickens had a satisfactory taste, aroma, and nutritional composition of the meat, confirming that BSF larval meal is suitable for inclusion in poultry diets (Cullere *et al*., 2018; Onsongo *et al*., 2018). According to Biasato (2019), BSFL is a suitable ingredient for animal feed formulation due to its associated benefits. The nutritional composition of BSFL, house fly maggots, mealworm, locusts, grasshoppers, crickets, and silkworm meal and their use as a replacement of FM and/or soybean meal in the diets of fish, poultry, pigs and ruminants have been discussed by Finke (2015). The CP contents of these insects are high ranging from 42% to 63% and lipids up to 36%. The concentration of unsaturated fatty acid is high in housefly, maggot meal, worm meal and house cricket (60-70%), while black soldier fly larvae have a lower concentration of 19-37%. Several studies have confirmed that palatability of these insects larvae meal to most animals is good and they can replace 25 to 100% of soybean meal or fishmeal depending on chicken feed requirements, age as well as the species (Makkar *et al*., 2014).

On the other hand fishmeal normally contains between 60% and 72% crude protein by weight. From a nutritional standpoint, fishmeal is the preferred animal protein supplement in the diets of farm animals and often the major source of protein in diets for fish and poultry and pigs. Soybean meal is the dominant protein supplement used in poultry diets and is the standard to which alternative protein sources are compared; with protein content of soybeans is 36–56% of the dry weight.

Black soldier fly is an interesting insect for the conversion of organic waste. It is shown that, it can efficiently transform pig waste, dairy waste and poultry manure to body mass, reducing dry matter mass up to 58% and associated nutrients including Phosphorus by 61–70% and Nitrogen 30–50%. It also has the ability to reduce house fly population in chicken manure. It is also shown that BSF larvae can efficiently reduce and recycle fish offal from processing plants. It has also been reported that insects release less greenhouse gases and ammonia as compared to cattle or pigs when retained together. They also pose less risk of transmitting zoonotic diseases to wildlife, humans and livestock compared with birds and mammals (Van Huis, 2013). The larval stage of BSF is described to diminish the quantity of pathogens such as *Escherichia coli* and *Salmonella enteric* serotype enteritidis on organic compost (Bullock *et al*., 2013; Nyakeri *et al*., 2017), hence making the residues safe for use in crop farming as organic fertiliser (Banks *et al*., 2014; Choi *et al*., 2009; Nyakeri *et al*., 2017). Black soldier fly larvae is a high value feed source rich in protein and fat, it contain about 40% CP. The amount of fat is extremely variable and depends on the type of substrate used to rear BSFL. For instance, its fat content is reported to be 15-25% DM (larvae fed on poultry manure), 28% DM (swine manure), 35% DM (cattle manure) and 42-49% DM (oil-rich food waste) (Newton *et al*., 2005).

2.2.3 Overview of Insects Incorporation as Livestock Feed in Kenya

Insects have been deemed as an appropriate ingredient for poultry feed when utilized in free-range or cage production systems (Anand *et al*., 2008; Das *et al*., 2012). Historically, insects have been part of Kenyan diets, especially in the western part of the country (Ayieko *et al*., 2010).

According to FAO/WHO (2005) and Global Agricultural Information Network (GAIN, 2005), the primary objective of Kenya's national food safety and quality system is to promote public health, safeguard consumers from health risks, and advance economic development. It is administered by a number of statutory government agencies that operate independently across multiple ministries. The government agencies include the Department of Public Health (DPH), the Kenya Bureau of Standards (KEBS), the Kenya Agricultural and Livestock Research Institute (KALRO), the Kenya Plant Health Inspectorate Services (KEPHIS), the Government Chemist's Department, the Department of Veterinary Services (DVS), the Kenya Dairy Board (KDB), and the Horticultural Crops Development Authority (HCDA).

Following the principles of the World Trade Organization's (WTO), Sanitary and Phytosanitary Standards (SPS) and Technical Barrier to Trade (TBT) agreements, the majority of Kenyan standards are derived from international ones, namely Organization for Standardization (ISO) and Codex Alimentarius Commission – Codex (CAC) (World Bank 2005). Standards pertaining to the use of insects as food and feed are currently receiving support, with conversations on forming a technical committee tasked with creating guidelines for their application currently taking place with the Kenya Bureau of Standards (KEBS) and other pertinent organizations.

Insects have gained an increasing amount of attention for their potential contribution to local economy, both in the feed and food sector (KEBS 2017). In 2017, Kenya Bureau of Standards approved the incorporation of dried insect products in formulated livestock feeds (KEBS, 2017). In Kenya, there is substantial commercial production of BSF by Insectipro and Sanergy companies. Consequently, KEBS has been at the forefront in formulation of policies and standards to guide the new venture. KEBS therefore, produced a draft guiding incorporation of insects as feed and food. The dried insects for compounding animal feeds -specification (KEBS, 2017) document was necessitated by massive attention from the large scale production of insects as an alternative protein source and its uptake as animal feeds by the stakeholders in livestock value chains. On the other hand, Code of practice (KEBS, 2020) on production and handling of insects for feed and food was formulated to ensure safe use of insects for food, feed and nutrition security.

2.2.4 Overview of Insects Incorporation as Human Food in Kenya

Insects have previously been mentioned in Kenyan dietary guidelines as a food source for nutrition security, for example, in the 2006 Kenyan National Guidelines on Nutrition and HIV/AIDS (mass-rearing insects for greener protein supply; GREEiNSECT, 2016). The edible insects within the Lake Victoria region are; termites, both green and brown grasshoppers, locusts and a collection of edible lake flies (Ayieko *et al*., 2010). Previous research along the Lake Victoria region on the incorporation of insects into value-added food products have mainly focused on termites and lake flies Kinyuru *et al*. (2009). According to Kinyuru *et al*. (2010), winged termites, grasshoppers, locusts, and crickets have been perceived positively as part of traditional diet among rural communities in Kenya. Lake Flies, termites, Black ants, locusts and Grasshoppers have traditionally been consumed by the locals in the communities that the insects are available in abundance (Alemu *et al*., 2015; Ayieko *et al*., 2010; Kinyuru *et al*., 2010).

Termites are part of the traditional diet in Western and Lake Victoria region of Kenya thus relatively popular even among non-insect eating communities (Weru *et al*., 2021). The greatest challenge in the use of edible insects is their seasonally in collection and perishability of the harvested insects by the surrounding communities (Ayieko *et al*., 2010).The most common sources of animal proteins in Kenya include dairy products such as milk, beef, chicken, eggs, fish fillet, dried small fish (*Rastrineobola argentea*) and edible insects such as termites (Republic of Kenya, 2006). Termites, *dagaa* and grain amaranth have been incorporated in formulation of protein rich complementary food for infants and mothers in Western Kenya region (*Konyole et al., 2012*). Termites can be consumed in different forms; such as whole insects, in powder or paste form, and as protein extract (FAO, 2010; Fellows *et al.*, 2014). Alemu *et al.* (2015), revealed that residents of Western Kenya mainly in rural areas traditionally consume whole termites after boiling or sun-drying or roasting them with a pinch of salt, accompanied with cornmeal.

According to the Republic of Kenya (2006), food security in HIV-affected households can be addressed in rural areas by incorporation of traditional practices of collection, preservation and consumption of indigenous foods such as edible insects like termites. It is especially recommended when planning for dry seasons when food is scarce among the community members (Republic of Kenya, 2006).Insects for food and insect-based food products are regulated in the same way as other foods by the Kenyan agencies that govern food safety control and consumer protection. Relevant agencies were identified which operate under four different ministries namely; Trade, Industrialization, Public Health and Sanitation, and Agriculture, Livestock and Fisheries, specifically the Livestock and fisheries department.

In Kenya, there is no recorded literature on incorporation of black soldier fly larvae as human food although approved the utilization of insects as food in Kenya in 2020, Code of practice (KEBS, 2020) on production and handling of insects for feed and food was formulated to ensure safe use of insects for food, feed and nutrition security.

2.2.5 Overview of Black Soldier Fly Producers in Kenya

Sanergy is a for-profit social enterprise registered in the United States of America, and based in Nairobi, Kenya, that operates organic waste and sanitation management systems, up cycling and converting waste to organic fertilizers and animal feed (Shields & Ruehle 2016; World Bank, 2019). Sanergy is the largest BSF producer in Kenya producing between 20-50 tons of dried BSF monthly. Besides its production capacity, the company is characterized by large, decentralized facilities namely; breeding units in a different location than production and processing units, size of operations in terms of land and number of employees, use of technology and processing equipment and access to international networks. The difference in the level of operations of Sanergy currently processes around 200 tons of waste per day. Mid-scale producers harvest ranges between 350 kgs-840 kgs of wet larvae and roughly 350 kgs-840 kgs frass per month with the higher production ranging from 1.2 - 4.2 tons of wet larvae and 1.5 - 5.6 tons of frass per month. The small-scale producers estimated to produce between 5 kilos to 20 kilos daily (FAO, 2023).

FAO (2023) reported that BSF farming is currently facing drawbacks, although many people have been trained in BSF farming, many of them have abandoned the business and it is difficult to determine how many are still actively farming BSF. Secondly, sector organization is in an early stage and the infrastructure and procedures to monitor farmers entering and exiting the sector are lacking. Nevertheless, it is estimated that there are 1200 active BSF producers. The BSF sector in Kenya is a relatively young sector since most BSF businesses in Kenya were founded from 2017 onwards with the exception of Sanergy that started BSF in 2014.

The BSF sector is characterized by a few large scale and well-known players with headquarters in or around Nairobi and a large body of small and mid-scale businesses scattered around peri-urban regions across the country. Higher concentrations of BSF businesses are located in Central Kenya (Nairobi, Kiambu, Kajiado, Machakos, the upper Rift Valley, and Nakuru) and in Western Kenya (Uasin Gishu, Kakamega, Kisumu, Homa Bay, and Siaya) as shown in figure 1.1 below.

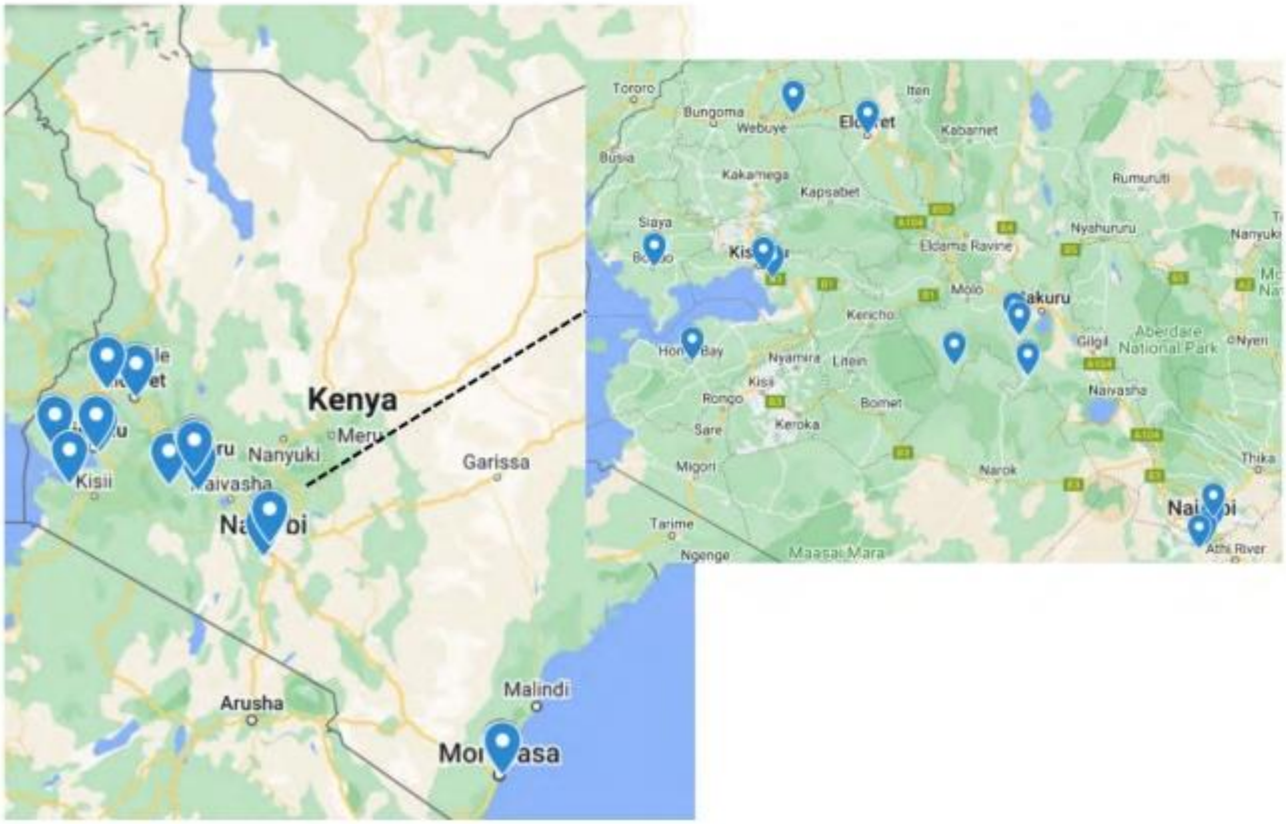

Figure 1:1 Location of BSF Producers in Kenya (FAO, 2023)

According to Kenya News Agency (2023), international Centre of Insect Physiology and Ecology (ICIPE) and other research institutions both Kenyan and international universities have taken up the subject of BSF farming, like Egerton University (RESSECT) unit, University of Eldoret with an established incubator for youth in Agriculture training on BSF farming working with local farmers as part of its community giveback, Jaramogi Oginga Odinga University of Science and Technology (JOOUST) operates a full cycle BSF farm on their campus in Bondo, the farm functions as both a Research and Development facility as well as a commercial entity. Through their projects, JOOUST works with 60 out-grower and youth groups whom they supply with a package of training and a starter kit comprising of love cage, eggs and substrate. Also, Aga Khan University in Mombasa, Kenya Agriculture and Livestock Research Organization (KALRO) and Jomo Kenyatta University in Nairobi are engaged in (pilot) projects on BSF farming.

Most producers sell their frass for Kes 40 per kg while the dried whole larva is selling at between Kes. 85 per kg and Kes. 120 per kg. The price range of wet larvae is quite substantial. The most common price for a kilo of wet larvae is Kes 400 per kilo gram, BSFL meal larvae also vary greatly between producers. However, larvae that are dried by producers using industrial driers fall into the price range of KES 125 – 150 per kg (FAO, 2023).

2.2.6 The Current BSF Policies in Kenya

In relation to BSF, there are three relevant documents generated by KEBS: Code of Practice for Insects in food and feed, Standard for Dried insects for compounding animal feed and a Standard for Organic Fertilizer.

2.2.7 Code of Practice for Insects in Food and Feed – KS2921/2020

According to KEBS 2020, the objective of this Code of Practice is to guide insect farmers in production of insects for food and feed. This Code of Practice extends beyond BSF farming and applies to all insects used in food and feed. The standard was developed to mitigate risks of insect rearing in the food chain whether in feed or in food. The Code of Practice introduces minimum requirements and guidelines to rearing including types of feed (waste), handling and processing.

Code of practice made reference to the International Platform of Insects for Food and Feed (IPIFF) policy on incorporation of insects in livestock feeds detailing overview of insects' production, harvesting and post-harvest handling techniques for safe use in commercial and own farm utilization by farmers and feed producing companies (IPIFF, 2020; Republic of Kenya, 2019). The focus of this policy is premised on the notion that commercialization of insect production is one of the avenues to alleviate poverty due to its positive association with wealth status from the revenues generated by the farmers (Cazzuffi *et al*., 2020). Code of practice further aim at increased integration of indigenous expertise on innovation and technologies geared towards of farmers' technical knowhow and production expertise (Republic of Kenya, 2019).

2.2.8 Dried Insects for Compounding Animal Feed - KS2711/2017

Dried insects for compounding animal feeds –specification document (KEBS, 2017) development was necessitated by massive attention from the large scale production of insects as an alternative protein source and its uptake as animal feeds by the stakeholders in livestock value chains. The document is specifically tailored to dried insects for compounding animal feed. The standard includes quality parameters for it to qualify as animal feed input, including moisture content, protein levels, and identification of minerals and fat content. In addition to these nutritional parameters there are safety parameters for microbiological components to prevent exposure of animals to contamination (KEBS, 2017).

2.2.8 Organic Fertilizer KS2290/2017

In 2017, KEBS issued a document on quality parameters for organic fertilizer, in the document it includes pH value of the product, carbon-nitrogen ratio of the final product, moisture content, temperature, nitrogen content, organic matter content to confirm organic nature of the product, and total primary Nitrogen Phosphorus K(Potassium) ratio by percentage. According to KEBS 2017, there are already a few BSF producers with certified organic fertilizer.

2.3 The Untapped Potential of BSF in Kenya

2.3.1 Circular Economy through Utilization of Organic Waste

Majority of people living in low to middle-income countries, such as Kenya, have inadequate sanitation and waste management systems that is rapidly increasing due to increase in human population and urbanization that result in increased demand for food and consumption, translating into more waste being generated (Hoornweg & Bhada-Tata, 2012), and the expansion of informal settlements that are not served by formal waste management and sanitation systems (Munala & Moirongo, 2011). As the urban population in Nairobi grows, so does the solid waste management burden, a situation that has been worsened by poor funding for urban sanitation departments and a lack of enforcement of sanitation regulations (The New Humanitarian, 2013)

According to Diener *et al*. (2011) and Nana *et al.* (2018) pre- and post-consumption food waste is the use of insects that feed on the organic resources to produce high-quality animal feed.

Specifically, the black soldier fly has a major role to play in shaping a circular economy system and ensuring that the nutrients in wastes are brought back into food value chains. During BSF larval stage, the BSF feeds voraciously on various types of organic waste, with a conversion efficiency of up to 80% waste biomass is thus converted into larvae, leaving a nutrient-rich and hygienic organic fertilizer (Nguyen *et al*., 2015). BSF has also been highlighted as potential recyclers of various types of wastes such as agro-industrial waste (Meneguz *et al*., 2018) dairy manure (ur Rehman *et al*., 2017), abattoir waste, food waste, fruits and vegetable waste, and human faeces (Lalander *et al*., 2019). This is an opportunity that can be explored in Kenya by large scale and commercial producers of BSF to address the waste management challenge and end up with organic fertilizer.

2.3.2 Creation of Employment Opportunities

Recent literature by Gender Equality in a Low Carbon World (GLOW, 2023) revealed that using black soldier flies presents an opportunity for women empowerment across the agricultural value chain in key windows along the value chain like waste management, larvae harvesting, processing and distribution. This can be achieved if BSF is adopted in numerous producers venturing to commercial BSF production in Kenya.

2.4. Chicken Production System in Kenya

In Kenya, major chicken feed categories are; chick and duck mash, growers' mash, layers' mash, broilers' mash, and Kienyeji mash. In these feeds, fishmeal and soybean meal are the major protein ingredients. However, reduced availability, high cost, and environmental implications of exploiting these resources have led to major constraints in achieving optimal production, especially for smallholder producers in Kenya (Okello *et al*., 2012). In Kenya, chicken makes up over 70% of the total chicken population. 90% of smallholder farmers rear indigenous chickens. Meat and egg consumption from those chickens contributes to food security for smallholders all over the country. It also represents an increase in revenues and creates a diversity of production and has an important role in income generation (Kingori *et al*., 2010). Chicken production promotes overall economic development. In comparison with other livestock, poultry has the advantage to have a low initial investment and a fast return, giving more than one marketable product, which requires low management practices (Kingori *et al*., 2010). Chicken also represents an important resource to face unexpected cash needs, which can occur in case of school fees or medical bills. 76% of the reared chickens are reared in a semi-free-range situation (Guèye, 2009).

Indigenous chickens are well adapted to the rural environment, and they can survive with low inputs. They are commonly left to search for food either around the house or in the field right after harvesting. Additionally, the flavour of indigenous chicken is preferred by consumers because of the flavour and also because of supposed organic production. Although their productivity is relatively low, indigenous chicken represents 47% of the national egg and 55 % of the national meat consumption (Onsongo *et al*., 2018). Chicken production is usually managed by youth, women, and landless people, and it has been promoted as a good secondary activity for those categories, allowing them to empower and improve their living conditions (Gueyé, 2009).

The composition of the Kenyan meat diet has shifted markedly from red meats to poultry. For example, from 1990 to 2013, on a *per capita* basis, beef consumption has declined by 6.4 percent, while chicken and turkey consumptions have increased by 37.9, and 42.5 percent respectively (Henchion *et al*., 2014). The growth in consumption especially for chicken is to some extent, attributed to its perception as a healthy alternative to red meats besides the low retail prices and ease of preparation, changes in income levels as well as changes in social class (Marshall *et al*., 2015). Also chicken meat is preferred by consumers in view of the perception that they are healthier and possess unique attributes such as distinct flavour, leanness, tenderness, and colour (Islam & Nishibori, 2009).

The sustainable utilization of insects in livestock feed formulation has the potential to transform the current over-dependence on fishmeal and soybean meal into a reliable circular economy that offers employment opportunities, especially for youths and women at the grassroots level with effective feedback to the environment (Gasco *et al*., 2020). The incorporation of insect protein, particularly the black soldier fly (BSF), in livestock feed formulation is being explored globally (Bbosa *et al*., 2019). In the European Union, whereas appropriate legislative steps are being initiated to integrate insect protein into feed formulation processes for poultry and pig production, the use of insects in fish feed has been approved (DiGiacomo *et al*., 2019).

In 2017, the Kenya Bureau of Standards (KEBS) approved the use of dried insect products in formulated conventional animal feed (Fiaboe & Nakimbugwe 2017). According to Chia *et al*. (2019), in Kenya, there are generated business models for insect-rearing for smallholder farmers in a way that would ensure profitability and environmental sustainability. There has been a growing interest by the private and public sectors in partnering with the International Centre of Insect Physiology and Ecology (icipe) to explore the use of insects for poultry feed. Nyakeri *et al*. (2017) demonstrated that the BSF is locally available in wild ecosystems in Kiambu, Bungoma, and Uasin Gishu as well as professionally bred by ICIPE and KALRO who offer training to smallholder farmers to multiply the number of BSF so that it can be available in a sufficient amount and easily harvested for commercial feed production.

2.5 Farmers' Perception of Insect-based Feed

Farmers' perception is the knowledge and behaviour of farmers regarding something (Maswadi *et al*., 2018). A farmer's decision to buy livestock feed depends on the perceived risks and benefits associated with the product. To ascertain the perception of various issues, marketing researchers have used rating scales. Perception represents an individual's or community's position in response to a situation. Perception is not directly observable, but responses to situations reveal attitudes (Likert, 1932). In this study, perception is defined as an understanding of the characteristics of BSFL-based feed. Herein, these characteristics of BSFL in chicken production are relative to feed performance, social acceptability of the BSFL-based feed, versatility of the feed, and marketability of meat and egg from chicken reared on the novel insect-based feeds.

Understanding farmers' perceptions provide an accurate reflection of their situation at hand, which could be a constraint to the uptake of agricultural innovations. Traditionally, insects have been associated with disgust and dirt and are considered to be pests as well as vector of transmitting diseases, hence the belief that they should be eliminated from the food-feed value chain (Pambo *et al*., 2017). Thus, understanding farmers' perceptions of insect-based feeds is an important starting point in initiatives that seek to improve livestock welfare through conscious feeding practices and effective management of their health (Okello *et al*., 2021).

Stakeholders; consumers, producers, and farmers should fulfil their expected contribution in an integrated way and all efforts should be put into preventive control and utilization of safe and quality animal feed. Bilateral communication that provides a channel for giving feedback among stakeholders is necessary to provide all information on the menace and risks associated with feed handling from the time of purchase and onwards (Klašnja-Milićević & Ivanović, 2018). A study conducted by Kelemu *et al*. (2015) on African edible insects for food in Kenya revealed that communities had positive perceptions on insects such as termites and crickets as food based on their cultural background, income and beliefs.

Also, a study by Chia *et al*. (2019) on Black soldier fly larvae as a sustainable animal feed ingredient in Kenya among pig and fish farmers revealed that pig and fish farmers had a positive attitude towards insects as feed, and are willing to pay for insect as a feed ingredient, also showed that insects are a nutritious feed ingredient for animals. On the other hand, Khaemba *et al*. (2021) in their study on consumers perception on chicken products derived from insect-based feed revealed that consumers of eggs and chicken meat positively perceived these eggs and were willing to consume them. Although a study by Okello *et al*. (2021) on farmers' perceptions of commercial insect-Based feed for sustainable livestock production in Kiambu County revealed that they had a positive perception; there still exist a gap because there is still scanty empirical literature documented either positive or negative on chicken farmers' perception on BSFL-based feed in Uasin Gishu County.

2.6. Determinants of Farmer's Adoption of Insect-Based Feed

A country's ability to fully utilise its agricultural potential depends on the innovativeness of the actors in the agricultural sector. The capacity of farmers and other actors to innovate in their production activities is dependent on the availability of technology (Lavison, 2013). Loevinsohn *et al*. (2013) define adoption as the integration of new technology into existing practice and is usually proceeded by a period of 'trying' and some degree of adaptation. Also Yokamo (2020) defines adoption as a mental process an individual pass through from first hearing about an innovation to final utilization of it. Adoption is in two categories; rate of adoption and intensity of adoption. The rate of adoption is the relative speed with which farmers adopt an innovation, which has as one of its pillars, the element of 'time'. On the other hand, the intensity of adoption refers to the level of use of a given technology in any period (Bonabana-Wabbi, 2002). According to Loevinsohn *et al*. (2013), farmers' decisions about whether and how to adopt new technology are conditioned by the dynamic interaction between the characteristics of the technology itself and the array of conditions and circumstances. Diffusion itself results from a series of individual decisions to begin using the new technology, decisions which are often the result of a comparison of the uncertain benefits of the new invention with the uncertain costs of adopting it. An understanding of the factors influencing this choice is essential both for economists studying the determinants of growth and for the generators and disseminators of such technologies (Udimal *et al*., 2017).

Conventionally, analysis of agricultural technology adoption focused on imperfect information, risk uncertainty, institutional constraints, human capital, input availability, and infrastructure as potential explanations for adoption decisions (Foster & Rosenzweig, 2010). A more recent strand of literature has included social networks and learning in the categories of factors determining adoption of technology (Uaiene, 2009). Akudugu *et al*. (2012) grouped the determinant of agricultural technology adoption into three categories namely; economic, social, and institutional factors. Khonje (2018) categorized the factors into, institutional characteristics and managerial structure. Moreover, Mwangi and Kariuki (2015) grouped them into institutional, economic, technological, and household specific factors classified them under human capital, production, policy, and natural resource characteristics. Categorization is done to suit the current technology being investigated, the location, and the researcher's preference, or even to suit client needs (Bonabana-Wabbi, 2002). For instance, the level of education of a farmer has been classified as human capital by some researchers while others classifies it as a household-specific factor. This study will review the factors determining the adoption of BSFL-based chicken feed by categorizing them into social, economic factors, farmers' institutional factors, and attributes of BSFL-Based feed. This will enable an in-depth review of how each factor influences adoption.

Therefore, availability of modern agricultural technologies to farmers and their ability to adopt and utilise them is equally critical. Unravelling the reasons for low technology adoption among farmers requires the specific factors influencing their decisions to adopt be identified. According to Ali and Behera (2016), technology makes farming easier than it could have been in its absence. Farmers' decisions on how and whether to adopt technology are conditioned by the dynamic interaction between features of the technology itself and the array of circumstances surrounding them.

According to Mwangi and Kariuki (2015), it is essential for the designers and disseminators of technologies to understand the factors influencing these decisions. Mignouna *et al*. (2011) in their study on the determinants of adoption of maize resistant variety found that farmers are likely to adopt technologies they perceive as compatible with their environment and consistent with their needs. It is also noted that farmers' perception of the characteristic of a technology positively influences their adoption decision (Akinbode & Bamire, 2015). Even though Akinbode and Bamire (2015), Lavison (2013), and Mwangi and Kariuki (2015), have conducted research on technology adoption, there is scanty literature on the specific factors determining the adoption of BSFL-Based feed in Uasin Gishu County. If the problem of low poultry productivity in Uasin Gishu County is to be addressed, then the gap of low adoption of BSFL-Based feed will be bridged. From the foregoing, this study aspires to examine the specific factors that influence adoption of BSFL-Based feed among smallholder chicken farmers in Ainabkoi, Soy and Kesses Sub-Counties in Uasin Gishu County in Kenya.

2.7. Costs and Benefits of using BSFL-based Feed and Fishmeal Protein Sources

There are many methods that can be used to determine the profitability of an enterprise as well as identifying the factors that influence profitability. Some of these methods include Gross Margin Analysis (GMA), value of production, total revenue, Partial Budgeting Analysis (PBA), Cost Effective Analysis (CEA), Cost Utility Analysis (CUA) and Cost-Benefit Analysis (CBA) (Van Schaik *et al*.,1996; Zweifel *et al*., 2009).

According to Abu *et al*. (2011) gross margin analysis is a simple model that is used to estimate the financial returns to a production process. It is used as a simple proxy for the profitability of a production process. Gross margin analysis (GMA) assesses economic efficiency of farm productions (Waweru & Spraakman, 2012). According to Semerci (2019) and Hatzakis *et al*.

(2010), Gross margin is the difference between the value of production and the cost of the production in an enterprise. A gross margin is a tool for budgeting and evaluation of implementation, typically for one year or a production season. As a budgeting tool, the gross margin helps to identify more profitable enterprises, calculate break-even price or yield and serves as building blocks of other farm budgets including the whole farm budget (Pedersen *et al*., 2006). As a tool for post-implementation evaluation, gross margin analysis has been used to compare the same or different enterprises over time and space (Heard *et al*., 2013).

Gross margin is the value obtained by subtracting variable expenses from the gross production value. This value represents an interest deposited on a capital by the proprietor, labour provision of the proprietor and family members, and naturally the sum of a profit (Demircan *et al*., 2006). Gross margin is one of the best performance measures for comparing an enterprise's operations given that it is unaffected by the size and nature of the business. The accounting entity should be adequate for a gross margin analysis, and it should be simple to distribute the variable costs. Calculating the gross margin is essential for business planning. According to planning assumptions, as the level of the enterprise operation rises, there will be a linear rise in the gross margin. In the gross margin analysis, it is a significant advantage that there is no need for a distribution of fixed costs to the enterprise operations. Thus, gross margin analysis has been embraced more in time and has been used largely. When the difficulty in distribution of fixed costs is considered, the gross margin analysis has been favoured as more clearly understood (Behera *et al*., 2008)

2.8. Analytical Framework and Empirical Studies on Perception and Adoption of Insect-based Feeds

Previous studies have applied factor scores as dependent variables in multiple linear regressions to understand farmers' perceptions. Asai *et al*. (2014) evaluated livestock farmers' perceptions of collaborative arrangements for manure exchange using multiple regressions based on principal component analysis in Denmark, in their study, they found out that socio-demographic characteristics of farmers, their production enterprises, their past experiences of transactions and spatial location of farms influenced their decision-making in establishing partnerships. Abebaw *et al*. (2006) in their study on coffee farmers' perceptions and sources of risk and the factors associated with them combined various farm and non-farm characteristics to compute factor scores that were used to elicit the determinants of coffee farmers' perceptions of risk, explained by a combination of family and farm characteristics, location attributes, human capital, access to information and other infrastructure.

In adoption studies, farmers' decisions to adopt a new technology depend on many complex factors. One such factor is farmers' perception of the characteristics of the new agricultural technology (Yazdanpanah & Monfared, 2012). Farmers' perception of agricultural technology influences their decision to adopt that technology (Agahi, 2011). According to Bagheri *et al*. 2008, a farmer's behaviour is determined by their perception of sustainable agriculture. Following the study by Asiedu-Darko (2014) on Improved Crop Varieties in Ghana, Farmers' perception of agricultural technology influences their decision to adopt that technology.

According to Oo and Usami (2020) in their study on Farmers' Perception of Good Agricultural Practices in Rice Production in Myanmar, descriptive analysis using average, standard deviation, percentage, variance, and a comparison was carried out to clarify the primary features of farmers' perception of GAPs in rice production. Furthermore, farmers were categorized based on their perception of GAPs in rice production through principal component analysis (PCA) and cluster analysis. Flaten *et al*. (2005) compared dairy farmers' risk perceptions with their risk management practices in Norway using factor analysis. Whereas factor analysis reveals latent variables representing farmers' perceptions of IBF, the OLS permits in-depth exploration of the factors to consider when advising governments, farmers, research institutions, and other stakeholders on insect based feeds.

To assess farmers' perceptions, they will be asked to rate their attitudes or perceptions on scales that are all positive ranging from highest to lowest, or, on scales that range from negative to positive. A Likert-type scale questionnaire is used to assess the degree to which they agree or disagree with statements on the benefits and risks of using the insect-based feed. Likert scale is preferred because it can be built into an index and there is little loss in accuracy when interpreting ordinal data is treated as an interval (Rose *et al*., 2014). To use the Likert scale, multiple statements are used in this type of questionnaire to implore various answers from respondents. Multiple statements are used because it is easier to measure perception with multiple statements than with a single statement (Rose *et al*., 2014). A five point continuum is the most efficient because it is easier to operate and saves on time when operating it on a principal component analysis.

According to Kothalawala *et al*. (2018) perception studies are usually categorized by developing an index or a score. Although there are few studies that have developed an econometric model inclusive of intrinsic values like perceptions due to the associated difficulties in accurate measurement of farmers' intrinsic features as well as interpretation of regression results (Asai *et al.,* 2014; Meijer *et al*., 2015). In such cases therefore, perception is accounted for by a wide range of statements measured using an ordinal scale. Thereafter, a linear reduction mechanism like principal component analysis is employed to point out the key behavioural patterns for further interactions with extrinsic variables (Oo & Usami 2020). Recent trace of literature postulates that, perception indices can be retained in continuous nature and be measured in regression analysis without looking at any perception indices threshold requirements (Asai *et al* ., 2014; Flatten *et al*., 2005). Therefore, multiple linear regressions method has been identified as the most appropriate for perception analysis because it generates perception index scores that are not correlated thus eliminating any instances of multi-collinearity issues as argued by Howley and Dollin (2012). Therefore, the current study considers this approach.

2.9. Theoretical Framework and Conceptual Framework

2.9.1. Theoretical Framework

The Theory of Planned Behaviour (TPB) was proposed by Ajzen (1985). The theory was developed from the theory of reasoned action which was earlier developed by Fishbein and Ajzen (1980). Theory of Planned Behaviour is based on the principle of understanding the person's choice of behaviour and to further examine the person's overall intention relating to that behaviour (Ajzen, 1991). The stronger the intention to engage in behaviour, the more likely should be its performance. According to TPB an individual intention to perform is determined by three variables: attitude, subjective norms and perceived behavioural control. TPB was discarded because while it does consider normative influences, it still does not take into account economic factors that may influence a person's intention to perform a behavior such as to uptake a technology.

On the other hand, Rogers' diffusion of innovation (DOI) theory is the most appropriate theory for investigating the adoption of innovation by small-scale farmers. Rogers (1995) defines diffusion as the process in which an innovation is communicated through certain channels over time among the members of a social system. He suggested that the diffusion process comprises four elements, namely: innovation, communication channels, time and social system (Wandera, 2020). Although the theory explains the four elements it does not explain how the factors that hinders the uptake of an innovation or a technology, therefore this theory is not sufficient to explain the factors that hinders technology uptake, therefore, the Unified Theory of Acceptance and Use of Technology (UTAUT) was considered. This theory has commonly been employed in many studies investigating hindrances to the acceptance, how a technology is perceived and use of technologies (Dulle & Minishi-Majanja, 2011; Kripanont, 2007; Zhou *et al*., 2011). The theory was proposed by Venkatesh *et al*. (2003) during their examination of factors influencing the intention of utilization and usage of information technology among 150 small manufacturing operators. The theory was developed based on the behavioural characteristics of the users and borrowed their tenets from eight models namely; the theory of Reasoned Action (TRA), the Technology Acceptance Model (TAM), the Motivational Model, the Theory of Planned Behavior (TPB), the combined TAM and TPB, the model of Personal Computer Utilization, the Innovation Diffusion Theory and the Social Cognitive Theory. Technology acceptance is about how people accept and adopt some technology to use (Alwahaishi & Snasel, 2013).

It is hence vital to predict and explain an individual's behaviour towards acceptance, how they perceive a given technology and the usage of technology. Various studies acknowledge that the UTAUT contributes to a better comprehension of the drivers of acceptance and use of new technologies than other similar theories (Al-Qeisi & Al-Abdallah, 2013; Dulle & Minishi-Majanja, 2011; Venkatesh *et al*., 2016). Previous studies (Alwahaishi & Snasel, 2013; Kripanont, 2007; Venkatesh *et al*., 2016) conducted using UTAUT have demonstrated that perceived ease of use and usefulness are central determinants of technology adoption, as long as they do not cause a significant increase in the production cost. For an innovation to be accepted, it has to be diffused well among the targeted end-users (Rogers, 2003). Therefore, the theory is cardinal to the study as it helped in explaining the behaviour exhibited by farmers towards acceptance and the usage of BSFL-based feed on their chicken.

2.9.2. Conceptual Framework

Figure 2.1 shows a diagrammatic representation of the conceptual framework of this study. The theory was used to model farmers decision making on whether to adopt BSFL-Based feed or not and its consequences thereof. The choice of variables was based on author's conceptualisation as well as insights gained from literature review. The diagram provides a link between Farmers' socio-economic characteristics, Farmers' Institutional characteristics, and Attributes of BSFL-Based feed, which all consequently affect farmer's perception on BSFL-Based feed as well as adoption of BSFL-Based feed with the outcome being choice of a cost effective protein source leading to improved smallholder chicken farming.

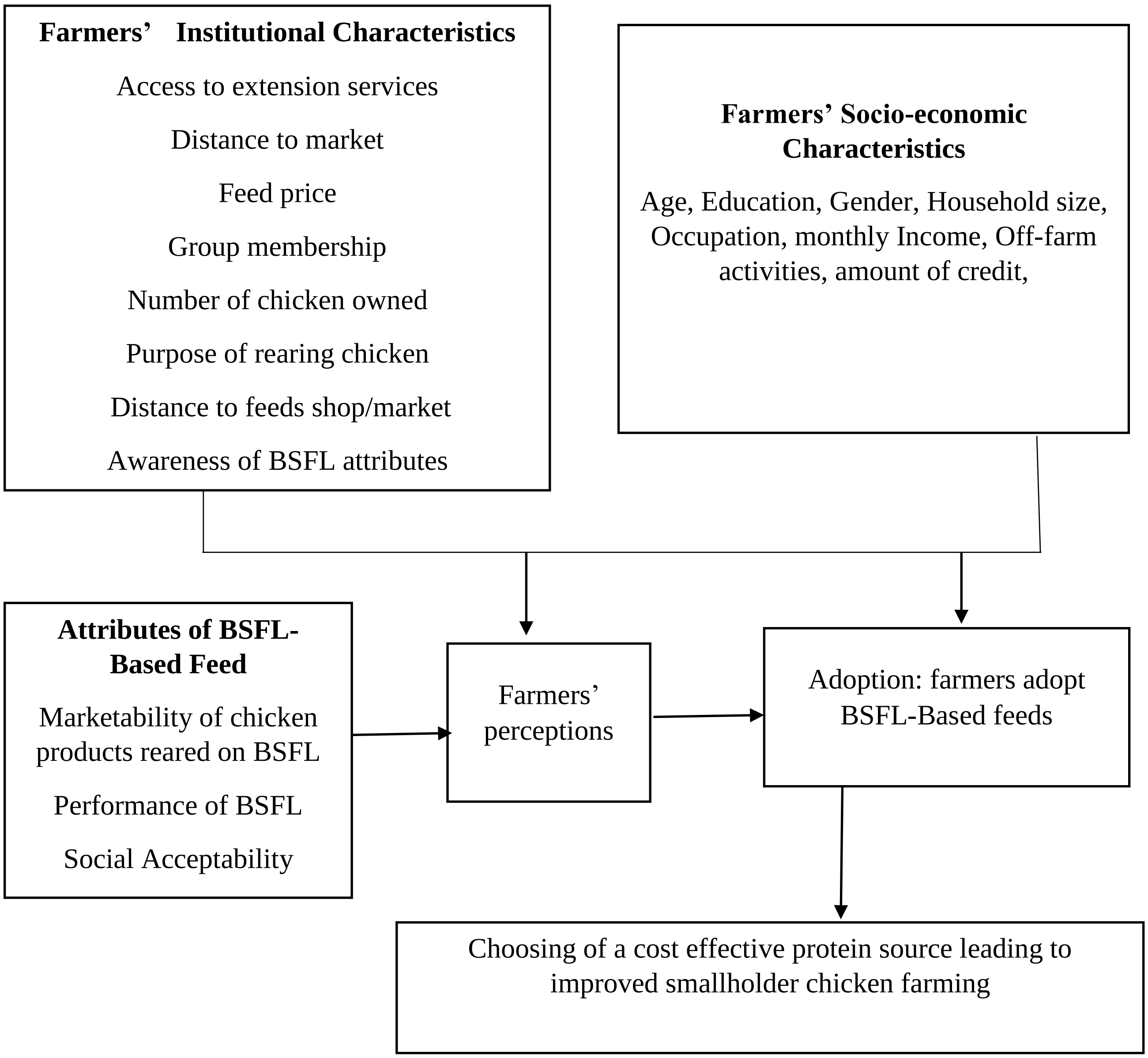

Figure 2:1 Conceptual Framework (Author's Conceptualization)

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The chapter gives information on the study area, sampling procedure, Sample size determination, data collection methods and sources and Analytical framework.

3.2 Study Area

The study was conducted in Uasin Gishu County. Uasin Gishu County has its headquarters in Eldoret town. The County extends between longitudes 340 50' east and 350 37' east and latitudes 00 03' South and 00 55' North. The County shares common borders with Trans Nzoia County to the North, Elgeyo-Marakwet County to the East, Baringo County to the South East, Kericho County to the South, Nandi County to the South West and Kakamega County to the North West (CIDP, 2018). It covers a total area of 3,345.2 km^2. The County experiences a high and reliable rainfall with an average annual rainfall ranging between 624.9mm-1560.4mm. It occurs between the months of March and September with two distinct peaks in May and August. The areas with relatively higher rainfall are found in Ainabkoi, Kapseret and Kesses whereas Turbo, Moiben and Soy receive relatively lower amounts of rainfall. The dry spells starts in the month of November and end in February. Average temperatures range between 7^0 C and 29^0 C. The rainfall and temperatures in the County are conducive for both agriculture and livestock farming (CIDP, 2018).

According to CIDP 2018, the number of poultry farmers in Kipsomba ward, Soy sub-county are 2612, while poultry farmers in Tulwet-Chuiyat ward in Kesses sub-county are 1840, and 1129 chicken farmers in Kapsoya, Ainabkoi Sub-county. It is further pointed out in GoK (2019) that, high unemployment level, food insecurity due to dependency on rain-fed agriculture, and high poverty and income inequality levels are a challenge in Soy sub-county in Uasin Gishu County. CIDP (2018) proposed that diversification of food production and encouraging self-employment should be promoted to enhance food security and poverty alleviation. Uasin Gishu county was purposively selected for its high population density, cosmopolitan population, and high number of smallholder chicken farmers coupled with projects promoting the chicken value chain by the provision of inputs such as *'Inua mama na kuku'* project as well as Kenya climate smart agriculture project that worked with smallholder farmers in promoting innovations, technologies and management practices such as black soldier fly as livestock feed, hay box brooder, thermo-stable vaccination, incubation and hatching using solar-powered incubators among other eco-friendly technologies.

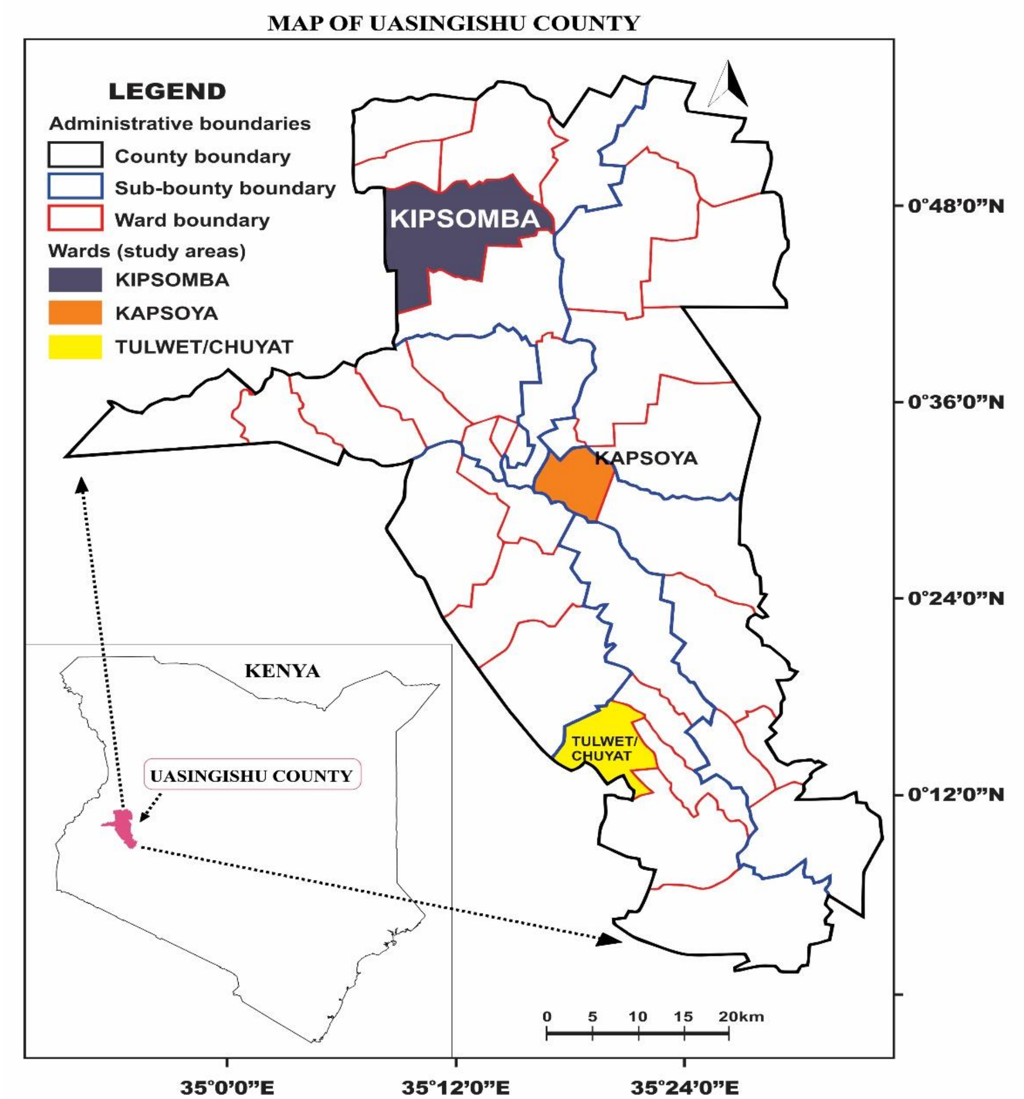

Figure 3:1 Map of the Study Area (IEBC, 2022)

3.3 Sample Size Determination

Previous literature on sample size determination provides various approaches to sample size determination such as using a sample size of a previous similar study, a census for a small population, use of published tables, and use of formulas (Al-Subaihi, 2003; Israel, 1992). Israel

(1992) postulates that when using Cochran's (1963) formula for an unknown population the sample size can be adjusted based on the desired confidence level, desired precision, and the degree of variability of attributes of interest in the population. This study employed Cochran's formula to determine the sample size due to the lack of reputable documentation on the exact population of the targeted respondents in the study area.

Israel (1992) provides suggestion for adjustment of the degree of variability or proportion. They recommend a proportion (p) of 80% in situations where the majority in the population have the desired attributes and (p) of 20% in cases where the majority in the population lack the desired attributes. This study adopted a (p) of 20% or 0.2 on assumptions that only a small proportion of the population will have the desired attributes, that is only a small percentage of the smallholder chicken farmers are already utilizing BSFL when formulating their chicken feed .A proportion of 50% or 0.5 which is commonly used is only applicable when there is maximum variability in the population (Al-Subaihi, 2003; Israel, 1992; Singh & Masuku, 2014)

$$n=\frac{z^2pq}{E^2}$$

The sample size, therefore, is;

$$n=\frac{1.96^2\times 0.2\times 0.8}{0.05^2}$$

n=245 farmers

where; n= desired sample size; Z= standard normal deviate at the desired confidence level (95%); p= proportion of the target population containing the major interest; *q= 1-p* the proportion of the target population that does not meet the characteristics of the research*; E*= allowable error. Since the proportion of the population is not known, *p*=0.2, *q*=1-0.2=0.8, *Z*=1.96 and *E*=0.05(acceptable marginal errors by the researcher) (Fisher *et al*., 1991)

The sample size was distributed according to the proportion size of the population within three wards from the three sub-counties in the study area.

3.4 Sampling Procedure

The study employed a multi-stage sampling technique. Uasin Gishu County was purposely selected because of the high number of poultry farmers and projects promoting the value chain actors. Soy, Ainabkoi and Kesses sub-Counties were purposely selected because of the higher number of smallholder chicken farmers compared to the other four wards. Tulwet-Chuiyat, Kapsoya and Kipsomba wards were randomly selected for the study. Finally, systematic sampling method was used to select households from the list of chicken farmers from a list that was provided by Sub-County Agricultural Officer. In systematic sampling method, the first respondent was randomly selected from the list and a sampling interval *k* was applied to obtain other respondents. k=N/n where k is the sampling interval, N is the total number of households in a given ward and n is the sample size in each ward.

Table 1: Sample Size Distribution of the Respondents in the Study Area

Sub-County	**Ward**	**Number of smallholder chicken farmers**	**Proportion**	**Number of respondents**
Soy	Kipsomba	2212	42.7%	105
Kesses	Tulwet-Chuiyat	1840	35.5%	87
Ainabkoi	Kapsoya	1129	21.8%	53
Total	**3**	**7852**	**100%**	**245**

3.5 Data Collection Methods and Sources

Prior to data collection the questionnaires were pre-tested on 30 smallholder chicken farmers in Tapsagoi ward in Turbo Sub-County in Uasin Gishu County. Thereafter, the data for this study was obtained from a cross-sectional survey of chicken farmers. Primary data was collected from the respondents by use of a semi-structured questionnaire Annex 1, the data collection exercise took 14 days. The respondents were interviewed individually as a way ensuring confidentiality of the data collected. Identifiers were used running from 001 until all the 245 respondents were interviewed, therefore respondents names were not used. Respondents were requested for consent prior to participation; details like phone numbers were not collected. The questionnaire contained the information on farmers' characteristics, socio-economic and institutional characteristics and BSFL attributes. They were administered through face-to-face interviews by trained enumerators. Thereafter the data collected from the questionnaires was entered in SPSS for management then transferred to STATA for analysis.

3.6 Analytical Framework

Objective one: To Determine Smallholder Chicken Farmers' Perception on BSFL-Based Feed in Uasin Gishu County.

Principal Component Analysis (PCA) was used to group the perception statements into clusters called principal components. The PCA was used to construct three perception indices that were used in a linear regression to assess the smallholder chicken farmers' perceptions on black soldier fly larvae-based feed. PCA is a well-known linear dimension reduction technique, which minimizes excessive number of correlated variables by incorporating new and relevant variables; the process reduces the dimensions of the data pool and permits for the extraction of key information from enormous data (Hair, 2010). The use of PCA was validated through the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy where a value of at least 0.6 was preferred (Kaiser, 1974).

Components with Eigen values of at least one were retained based on the Kaiser criterion (Montgomery *et al*., 2012). Further, the component loadings were subjected to an orthogonal varimax rotation to produce uncorrelated factor scores for ease of interpretation. PCA is important in compressing the size of the data by extracting the most important information, simplifying the description of the data set and analysing the structure of observations and variables (Abdi & Williams, 2010).

The uncorrelated components accounted for the total original variance. The very first Principal components chosen had the greatest variance with the highest percentage of explained variance, which is an index of goodness of fit; the remaining components with low percentages of explained variance were dropped (Cappellari *et al*., 2003). The reduced dataset (groups) were then used as dependent variable subsequently in the linear regression model to evaluate factors influencing farmers' perception of BSFL-Based feed among smallholder chicken farmers in Uasin Gishu County.

$$P_i = \sum_{i=1}^{k} b_k \, (a_{ik} - a_k)/s_k \tag{1}$$

where; P_i is the perception index for the i*th* farmer, *bk* represents the weights/factor loading of the *kth* perception statement; *aik* is the response of the *ith* farmer for the *kth* perception statement, *ak* and *Sk* were the mean and standard deviation of the *kth* perception statement.

This study estimates four multiple regression equations. The dependent variables of the four equations are perception indices computed using the PCA method. The indices comprise of three individual BSFL-Based feed component indices derived from the factor scores of three key BSFL perception components (performance, acceptability, and marketability) and a composite index of the three individual BSFL-Based feed components. Montgomery *et al*. (2021), specified the OLS as a linear equation of the parameters as follows:

$$Yn = Xk\beta x + \varepsilon \tag{2}$$

where Y*n* is the n*th* factor score, β*k* denotes the vector of the parameters to be estimated; X*k* is the vector of the farmer specific characteristics such as: age, gender, education level, monthly income, awareness of incorporation of insects in animal feeds, participation in off farm activities, number of contacts with extension officers, and membership in poultry groups, while *ε* captures the statistical random term that accounts for measurement error.

Objective two: To Identify the Factors Influencing the Adoption of BSFL-based Feed among Smallholder Chicken Farmers in Uasin Gishu County.

To determine the socioeconomic, institutional factors and BSFL characteristics influencing smallholder chicken farmers' adoption of BSFL-Based feed in Ainabkoi, Soy and Kesses Sub-Counties, it was analysed using binary probit model. The decision to use BSFL-Based feed among the smallholder chicken farmers is discrete, mutually exclusive and dichotomous (binary), where a chicken farmer can decide to use or not to use BSFL-Based feed on their flock.

Therefore, the decision to uptake the BSFL technology is considered as a qualitative dependant variable in a regression model with a value of 0 for non-adopters or 1 for adopters. It also depended on farmer's socio-economic and institutional characteristics and BSFL attributes. From the literature review on technology adoption, there are some types of models commonly used to analyse the decision to use or not an agricultural technology such as linear probability model, logit, and probit. Etoundi and Dia (2008) noted that the linear probability model often had a disadvantage to define the forecast probability beyond the [0-1] interval.

Probit model was the most appropriate model in analysis of perception studies. Morimune and Kunitomo (1980) cited by Etoundi and Dia (2008), chicken farmers chose either BSFL-Based feed or fishmeal based. The uptake of one or the other protein incorporated was more likely due to variation in chicken farmers' expectations. Therefore, this study employed binary probit model as a tool to analyse the factors influencing the adoption of BSFL-based feed due to its ability to constrain the decision to use BSFL which lie between 0 and 1 and most importantly, it resolves the heteroscedasticity problem, it also assumed normal distribution of the data (Asante *et al*., 2011; Wiboonpongse *et al*., 2012).

The variables that were used in this model are described in Table 2, a binary probit is characterized by a set of binary dependent variables (Y) then the resulting equation system is represented below:

$$Y_i = \beta X + \varepsilon_i \tag{3}$$

where Y_i is an unobserved (latent) random binary variable that defined chicken farmer's adoption of BSFL-Based feed, X is a set of explanatory variables associated with individual *i*. β is a vector of coefficients associated with the explanatory variables while ε_i represents the random error terms. The relationship between the unobserved variable and the observed outcome can be specified as:

$$Y_i \begin{cases} 1\ if\ > 0 \\ 0\ Otherwise \end{cases} \tag{4}$$

Maximum likelihood estimation (MLE) was used to estimate the probit model of the research due to its maximum properties and asymptotically efficiency in large samples (Chou *et al*., 2016). The probit model was derived from the linear probability model to estimate the equation below:

$Y_i = \beta_{0+}\beta_1 AGE_{+}\beta_2 GEN+\beta_3 EDUC+\beta_4 HHSIZE+\beta_5 OCC+\beta_6 OFFFIN+\beta_7 GRPMEM+\beta_8 DIST+\beta_9 AGRIEXTEN+\beta_{10} AWARN+\beta_{11} PURP+\beta_{12} CHICKNUM+\beta_{13} CRDT+\beta_{14}\text{MINCOME}+\beta_{15} FEEDP+\beta_{16} YRSOFFARNG+\beta_{17}\text{ SOURC}+\varepsilon_i$ *(5)*

where: AGE is the age of the respondent, GEN gender of the individual making decisions with regard to buying and selling for the chicken, EDUC level of education, HHSIZE the household size of the respondent, MINCOME respondent's monthly income(monthly expenditure), OCC occupation of the decision maker for chicken buying and selling, OFFFINC participation in off-farm activities, GRPMEM group membership, DIST distance to the nearest feed shop, AGRIEXTEN number of contacts with agricultural extension officers, AWARN awareness of the respondent on BSFL feed, PURP purpose of rearing chicken, CHICKNUM number of chickens owned by the respondent, CRDT is amount of credit borrowed, SOURC is source of credit, YRSOFFARNG is number of years in farming.

Table 2: Description of Variables in Probit Model

Variable	**Description**	**Unit**	**Measurement**	**Expected sign**
Dependent variable				
Y_i	Adoption of BSFL-Based feed	Dummy	1: Adopters 0:Non-adopters	
Independent variable				
AGE	Age of household head	Continuous	Years	+/-
GEN	Gender of the household head	Dummy	0:Male 1:Female	+/-

EDUC	Education level of the respondent	Categorical	1=no formal education 2=primary education 3=secondary education 4=tertiary education	+/-
MINCOME	Monthly expenditure	Continuous	Kes	+/-
HHSIZE	Total members of the household	Continuous	Persons	+/-
OCC	Occupation of the respondent	Categorical	1: Farmer, 2: Civil servant, 3: Self-employed	+/-
OFFFINC	Participation in off-farm activities that generate income for the respondent	Dummy	1=yes, 0=no	+/-
CHICKNUM	Number of chicken owned by the respondent	Continuous	Chicken	+/-
GRPMEM	Whether the household head belongs to any poultry farmer group	Dummy	1=Member 0=Otherwise	+/-

AWARN	Whether the respondent is aware of the BSFL incorporated in poultry feeds	Dummy	1: Awareness 0: Otherwise	+/-
DIST	Distance the household covers to the feeds shop to purchase feeds	Continuous	Kilometres	+/-
FEEDP	Retail price of chicken feed in Kilograms	Continuous	Kes	+/-
PUPR	The purpose of rearing chicken either for commercial or for own consumption	Dummy	Commercial =1 Own consumption=0	+/-
AGRIEXTEN	Number of contact with agricultural extension officers	Continuous	Number of times	+/-
SOURC	Source of credit	Categorical	1= Commercial banks ,2=SACCO 3=Informal lenders 4=Farmer group,5=grants	+/-
YRSOFFARNG	Number of years the respondent has	Continuous	Years	+/-

	in farming chicken			
CRDT	Amount of credit borrowed or received as grants in Kes	Continuous	Kes	+/-

Objective three: To Determine the Costs and Benefits of using Black soldier fly Larvae Compared to Conventional Protein Source in Uasin Gishu County

A number of economic approaches such as cost-effectiveness analysis, multi-criteria analysis, social return on investment and willingness to pay can be used to assess the costs and benefits of technologies adoption in agriculture (Atkin *et al*., 2017; Bai *et al*., 2019; Khatri-Chhhetri *et al*., 2017; Liu *et al*., 2016). Although cost benefit analysis (CBA), which explicitly quantifies and monetizes all the costs and benefits of an intervention and technology and facilitates systematic consideration of the various factors that influence strategic choices(Boardman *et al*., 2004), is widely used, it can sometimes be challenging for them to predict certain variables, such as customer demand and material prices.

Therefore, Gross Margin Analysis approach was used to determine the cost and benefits of using BSFL-Based feed in comparison to other protein sources**.** Gross margin was calculated by subtracting total variable costs from total revenue (FAO, 2016). The advantages of the GMA as an economic tool include its easiness to understand and utilize the logical interrelations of economic and technological parameters and its ability to forecast rational variants for the operational structure of an enterprise or individual farmer. In addition, GMA is an easy way to understand profitability of an enterprise as it shows how effective management can bring profits from sales and how an enterprise can minimize competition (McClure, 2004). Employing gross margin analysis allowed for the determination of smallholder chicken farmer's profitability based on the two different protein sources. It is also a method for choosing farm plans.

Additionally, it helped in determining whether or not the pricing of farm products or services were appropriate. It also helped in responding to changes in the cost of materials, which affect farm margin directly.

The model was specified as follows:

$$GM = TR - TVC \quad (6)$$

where: GM is gross margin of smallholder chicken farmers; TR is Total (Gross) Revenue; TVC is Total Variable Costs.

The production cost can be classified into variable costs and fixed costs. A variable cost is a farms' expense that changes in proportion to how much a farmer produces during a production season. Variable costs may increase or decrease depending on a farms' production or sales volume they may rise as production increases and fall as production decreases. On the other hand fixed cost includes expenses that remain constant for a period of time irrespective of the level of outputs or production which may include rent, salaries or wages, and loan repayments.

However, gross margin analysis did not include fixed or overhead costs such as depreciation, incubator purchased, or permanent labour costs and comparison can be misleading because fixed costs vary for different farms (Firth, 2002). The gross (total) revenue was calculated using the stated price of mature hens, mature cocks and eggs multiplied by the number produced per household that the reported by the survey respondents. Quantity produced included total amount produced and marketed, consumed at household level, or gifted out. The only direct and measurable return was obtained from the sale of chicken and chicken products. TVC included veterinary cost which comprises of vaccination and treatment, dewormers, feeds, and labour. In this case, current season's (2021/2022) prices and labour costs were used.

Total revenue was obtained by multiplying the volume of output by their respective prices as follows;

$$TR = P_y Y \quad (7)$$

Whereas total variable cost was obtained by accounting for all the costs incurred during the production process as follows;

$TVC=P_xX$ (8)

GM calculated using the following formula below.

$GM=\sum P_yY-\sum P_xX$ (9)

where Py is Unit price of Hen/Cock/Egg Px Unit price of inputs used in chicken rearing, Y and X Quantities of output and inputs in respectively.

According to Akani and Akani (2018), gross margin is an important analytic tool to assess the profitability of different farming enterprises, although it has a number of disadvantages. These are;

i. There is no inclusion of fixed costs in the analysis. Therefore the analysis is incomplete. The exclusion of fixed cost is because fixed costs vary from one chicken farmer to the other.

ii. Gross margin analysis does not take into account the possible environmental and social effects that may arise due to different types of technology adopted. This did not affect the outcome of the study, since it is only one technology (black soldier fly larvae in comparison to fishmeal).

iii. The results of a gross margin analysis are only valid for the season under consideration; therefore, they may be not useful for other recommendations.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter is divided into four major sections. The first section discusses the descriptive results comprising of households' socioeconomic and institutional characteristics of the adopters and the non-adopters. In the second section, principal component analysis results are discussed. The results of binary probit regression model and gross margin analysis model are discussed in sections three and four respectively.

4.2 Descriptive Results

There were 93 smallholder chicken farmers utilizing black solder fly larvae as an alternative protein source, whereas 152 smallholder chicken farmers out of the 245 sampled respondents were utilizing fishmeal on their chicken, an implication that the adoption rate is still low at 38%.

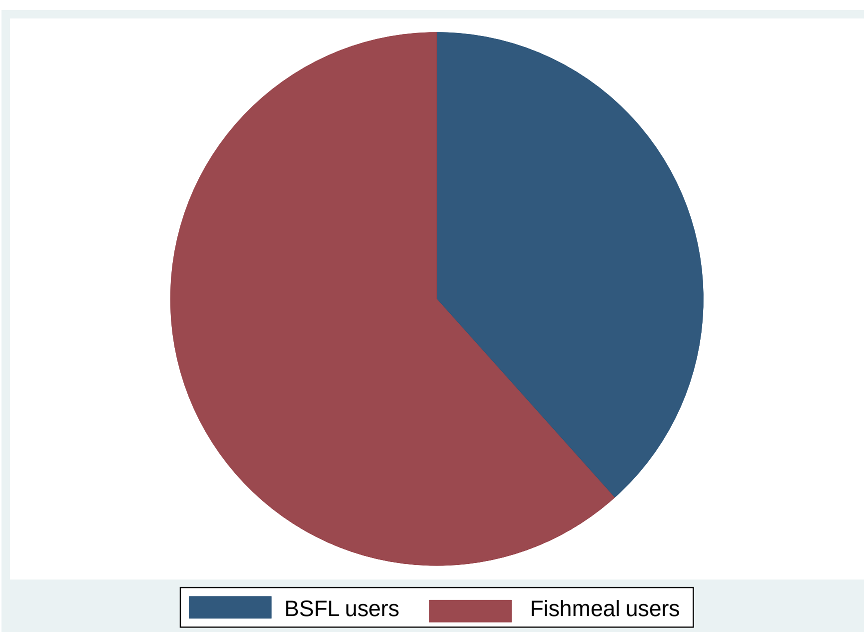

Figure 4: Pie chart of 93 adopters and 152 non-adopters

4.2.1 Farmer characteristics

The results of gender of the decision makers with regards to buying and selling chicken feeds and chicken products and education level of household head are presented in Table 3. In terms of the gender of the household head of Black soldier fly larvae users, 65 were female while 28 were male. Among the fishmeal users, female were 110 whereas 42 male. Hence, majority of the decision makers for chicken production were female.

Education level of the decision makers with regards to buying and selling for chicken was broken down into four categories, no formal education, primary education, secondary education and tertiary education. There was a significant difference in education level of the decision makers between the two groups at 1% level. Among the black soldier fly larvae users, majority 52.2% of the farmers had attained tertiary education compared to 9.5% of the fishmeal users. Conversely 25.5% of adopters had secondary education compared to only 11.1 % of non-adopters.

Table 3: Gender, occupation and education level of the smallholder chicken farmers

Variable	Adopters (Black soldier fly larvae users) (N=93)	Non-adopters (Fishmeal users) (N=152)	x^2
Gender			
Female	65	110	0.045
Male	28	42	
Education level %			
No formal education	6.6	48.9	
Primary education	17.7	30.5	
Secondary education	25.5	11.1	
Tertiary education	50.2	9.5	10.02***
Occupation %			
Farmers	77.12	64.20	

Civil servant	7.76	22.24
Self-employed	15.12	13.56

**=significant at 5% level.

Overall, education level for the adopters was significantly higher than the non-adopters. This might have made them able to understand the importance of using the new agricultural technology, which is black soldier fly larvae. Education level allows farmers to comprehend and understand the importance of utilizing black soldier fly as an alternative protein source. Therefore, highly educated farmers are likely to be innovative and open minded to use new technologies such as insect-based feeds. Teklewold *et al*. (2013) found that higher level of education empowers farmers in adoption of new technologies in their agricultural ventures.

4.2.2 Household characteristics of smallholder chicken farmers

The mean differences of household characteristics in terms of age of the decision makers regarding buying and selling for chicken feeds and chicken products, household size, number of chicken kept by the smallholder chicken farmers and the number of years the farmers have been rearing chicken for the two groups; adopters of black soldier fly larvae and fishmeal users are presented in Table 4.

Table 4: Mean of household characteristics of smallholder chicken farmers

	Adopters		Non-adopters		
Variable	mean	Standard deviation	Mean	standard deviation	*t*-test
Age(years)	38.2	7.54	49.6	10.96	4.673**
Household size	5.1	1.25	5.9	1.94	2.953
Number of chicken kept per farmer	98	13.7	106	17.9	2.93
Number of years of rearing chicken	11	5.2	17	9.3	3.62

**=significant at 5% level.

Concerning the age of the decision makers for the two groups, adopters had a mean age of 38.2 years while non-adopters had a mean age of 49.6 years. The association between adoption and age of the household heads was statistically significant at 5%. Age of the decision maker plays a vital role in usage of new agricultural technologies. Adopters of black soldier fly larvae were younger than the fishmeal users possibly because young farmers tend to be innovative and risk takers thus would try technologies than older farmers who tend to be risk averse.

The mean household size of adopters was 5.1 years and 5.9 for non-adopters. On average the number of chicken kept by black soldier fly larvae users was 98 whereas, the fishmeal users kept an average of 106 chicken. Finally, on average the black soldier fly larvae users had been rearing chicken for an average of 11 years while their counterparts have been rearing chicken for an average of 11 years.

Table 5: Household distance to market and number of contacts with extension officers

Variable	Adopters of (BSFL) Mean	Standard deviation	Non-adopters Mean	Standard deviation	*t*-test
Contacts with agricultural officers	3	1.11	2	0.78	2.072***
Distance to the market(kms)	5.1	1.54	6.9	1.02	1.681

*** Significant at 1% level

Farmers having contacts with agricultural extension service facilitates the dissemination of new agricultural knowledge and information sharing to smallholder farmers. Among the adopters of black soldier fly larvae, they had a mean of 3 extension contacts within the last production season while the non-adopters had a mean of 2 contacts. Black soldier fly larvae users had higher extension contacts, the association between use of insect-based feed and extension contacts was statistically significant at 1%. Accessing agricultural extension services provides farmers with agricultural information needed in use of agricultural innovation and technologies. They are also important in the dissemination of new technologies and consequently affect their effect on household welfare (Mwaura *et al*., 2014). The average distance of the households to the input and output market was longer for fishmeal users at 6.9 kilometers whereas for the black soldier fly larvae users were 5.1 kilometers.

4.2.3 Institutional characteristics

Table 6 presents the institutional characteristics of the adopters of insect-based feed and the non-adopters of insect-based feed for dummy variables.

Table 6: Institutional characteristics for dummy variables

Variable		Adopters	Non-adopters	χ^2
Group membership	Yes	69.6	52.4	11.114**
	No	30.4	47.6	
Participation in off-farm activities	Yes	71.3	64.4	9.716
	No	28.7	35.6	

Belonging to poultry groups can play a vital role in facilitating farmers' uptake of black soldier fly larvae, a new agricultural technology. Among the adopters 69.9% of the respondents were involved in group activities in contrast to 52.4% of non-adopters. The association between uptake of black soldier fly larvae as an alternative protein source and group membership is statistically significant at 1%. It is therefore evident that utilizing lack soldier fly larvae in the households is influenced by belonging to poultry groups. This could be due the knowledge sharing by farmers in groups during group meetings which enables them to learn about new agricultural technologies, hence trying them on their chicken as opposed to their counterparts. This finding is in conformity to Barret (2008) who found group membership acts as an avenue for sharing information, accessing market for their products hence a reduction in information asymmetry among the market players.

4.2.4 Description of the Chicken Farmers' Perception Indicators of BSFL-Based Feeds

The questionnaire included a total of 18 perception statements were the respondents were asked to rate their level of agreement on a five-point Likert scale on agreement or disagreement ranging from 1 (strongly disagree) to 5 (strongly agree). A PCA was used to reduce and group the statements into three broad BSFL-Based feed perception attributes, that is, acceptability with 6 retained factors, marketability with 3 retained factors and lastly performance of BSFL-Based feed in comparison with conventional fishmeal on chicken 3 retained factors.

The perception statements were based on a range of livestock performance indicators such as safety, growth, feed intake and socio-economic factors such as consumer acceptance of chicken reared on BSFL, and feed prices and the impact of BSFL on the chicken products prices. Each of the three individual perception indices had a standard error of zero and a standard deviation of one for marketability index, performance index and acceptability index whereas the composite index had slightly higher standard deviation of approximately 1.4 due to the aggregation effect of the three perception indices to collectively form the composite perception index illustrated in Table 7.

The composite perception index was developed under principal component analysis model by aggregation of the three perception indices to obtain an overall perception index that portrays the overall smallholder chicken farmers perception on black soldier fly larvae as an alternative protein source.

Table 7: Description of the Chicken Farmers' Perception Indicators of BSFL-Based Feeds.

Variable	Description	SE	SD	Min. value	Max. value

Acceptability	New innovations and technologies that are guided by the beliefs and social dynamics of the community	0.028	1	-3.235	2.245
Marketability	Cautiousness of how consumers of chicken products may perceive changes to chicken diets.	0.063	1	-0.987	1.986
Performance	The nutritional composition of the feed and notable indicators that farmers can monitor	0.047	1	-1.879	3.075
Composite perception index	The overall index best describing perceptions about BSFL-Based feed wholly	0.027	1.4	-7.101	7.306

4.2.5 Chicken Farmers' Ranking of Perceptions of BSFL-Based Feeds

Smallholder chicken farmers' level of agreement with the various BSFL attributes ranking are presented in Table 7. The mean scores range was between 3.66 and 4.49 with values closer to five indicating more favourable perceptions and values closer to value one suggesting less preferred perceptions of BSFL, based on a five-point Likert scale. The statement, "BSFL-Based feed should have special features for easy identification by farmers'' had the highest mean score ranking of 4.49, "I am willing to use BSFL once it is commercially available'' with a mean of 4.13, ''BSFL is acceptable in my culture'' with a mean of 4.07, "BSFL is acceptable in my religion'' with a mean of 4.06, which implies that BSFL as an alternative protein source is socially accepted showing its religious and cultural appropriateness indicating favourable societal acceptance of BSFL in Uasin Gishu County by the smallholder chicken farmers. The idea of feeding BSFL to all types of livestock had a lower mean of 3.71, the possible explanation could be that smallholder farmers kept more than one type of livestock on their farm like cows that are kept for milk that were fed with specific type of meal, hence the reason for the low mean recorded.

Smallholder chicken farmers' perception of consumer acceptance of chicken products reared on BSFL had a mean score of 3.98 suggesting that consumers would buy chicken meat and eggs derived from BSFL-Based feeds over other protein based feeds. This finding is in line with Khaemba *et al*. (2021) who asserted that consumers of eggs derived from chicken reared on BSFL had a positive perception. Also these results are consistent with the findings of Okello *et al*. (2021), who argued that farmers in Kiambu County had a positive perception on Insect based feed as an alternative source of protein for their livestock.The communalities obtained from the PCA that ranges between 0.3 and 0.8 with only two perception statements recording communalities extraction value of above 0.8, an indication of a weak association between the variables used in the PCA model (Hauben *et al*., 2017) hence the model was suitable for the data.

Table 8: Smallholder Chicken Farmers' Ranking of Perceptions of BSFL-Based Feeds.

Rank	**Rankings of smallholder farmers' perceptions of BSFL-Based feed**	**Mean**	**SD**	**Communalities**
1	BSFL-Based feed should have special features for easy identification by farmers	4.49	0.739	0.443
2	BSFL is acceptable in my religion	4.06	0.621	0.660
3	Insects have high protein content	4.00	0.921	0.765
4	Chicken fed on BSFL will grow faster	3.66	0.715	0.802
5	I am willing to use BSFL once it is commercially available	4.13	1.080	0.637
6	The level of knowledge influences the willingness to purchase insect feed	4.06	1.156	0.715
7	BSFL will lead to affordable chicken products	4.10	0.691	0.395

	price			
8	BSFL is acceptable in my culture	4.07	0.568	0.478
9	Buyers and consumers of chicken products will buy products that were fed on BSFL	3.98	1.266	0.827
10	BSFL will result in affordable chicken feed price	3.89	0.956	0.387
11	Insect production can contribute to increase the income of families in low-income areas	3.92	0.407	0.650
12	BSFL can be fed to all livestock	3.71	1.361	0.443

Note: scale ranging from 1 (strongly disagree) to 5 (strongly agree)

4.2.6 Principal Components of Chicken Farmers Perceptions of BSFL-Based feed and their Associated Loadings

Prior to the extraction of factors, pre-estimation tests were conducted to assess the suitability of the data and adequacy of the sample size for the principal component analysis. The data was screened for outlier values by observing the factor loadings on each of the factors that were analysed for the model. As a result, variables that had factor loadings of less than 0.30 were identified and dropped a test that strengthened the Cronbach's alpha (Olivier *et al*., 2018). Excluding the loadings that were less than 0.30 yielded a three-factor solution from 4 factors that recorded an Eigen value of 1. Premised on literature regarding the appropriate or minimum sample size for the principal component analysis to be effective, the data was satisfactory for the model as a sample size of at least 100 has been suggested to be sufficient, since the survey was conducted on 245 smallholder chicken farmers then it was sufficient as it was above the minimum threshold (Browne, 2009; Olivier *et al*., 2018; Teryima *et al*., 2016).

Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of Sphericity were conducted prior to the principal component analysis to determine if PCA was a suitable model for this data. The pre-estimation tests proved that PCA was a suitable model since it resulted in a KMO of 0.687 with an associated p value of less than 0.001. This indicated that the sampling was adequate for PCA as a KMO of at least 0.6 has been suggested to be suitable, thereby, revealing that partial correlation was minimal (Glen, 2017; Olivier *et al*., 2018). Cronbach's alpha for reliability was conducted. According to Kaiser (1974) and Teryima *et al*. (2016), the Cronbach's alpha should at least be 0.5. In the current study a Cronbach's alpha of 0.851, 0.546 and 0.726 was obtained for acceptability component, marketability component and performance component respectively. A Cronbach's alpha of 0.851 indicated that 85.1% of the 18 perception statements that were used in determining the smallholder chicken farmers perception were consistent (Dhir & Tsai, 2017; Olivier *et al*., 2018), this revealed that there was a good internal consistency and reliability, further indicating that Principal component analysis was a suitable model for this data.

The outcome of the retained principal components and the corresponding loadings from each of the 12 perception statements are shown in Table 8. The Cronbach's alpha, a measure of internal consistency, for each factor score was above the threshold of 0.5 hence the perception statements were reliable for PCA. According to Kaiser (1974), the KMO test of sampling adequacy should be between 0.6 and 1; this study recorded a KMO of 0.687 which is within the recommended threshold. Based on the Kaiser criterion, the retained factors cumulatively explained about 60% of the variation. The marketability component explained the maximum variation of 27.96% with 6 items showing factor loadings above the threshold of 0.5 for retention of statements, marketability component explained 19.98% and lastly performance component of BSFL explained 12.89%.

Chicken farmers recognisably agreed with statements such as, "BSFL is acceptable in my religion'', "BSFL is acceptable in my culture'', "BSFL will lead to affordable chicken product price'', and "BSFL will result in affordable chicken feed ingredient'', "BSFL-Based feed should have special features for easy identification by farmers'', and "Insect production can contribute to increase the income of families in low-income areas'' were all under the acceptability index, which cumulatively explained 27.96% of the variation and with the six statements recording factor loadings above the 0.5 threshold. On the other hand, it was notable that farmers indicated that, "I am willing to use BSFL once it is commercially available'', "the level of knowledge influences the willingness to purchase insect feed'', and lastly, "buyers and consumers of chicken products will buy meat and eggs that were fed on BSFL''. The perception statements satisfied the 0.5 factor loading threshold, and cumulatively explained 19.96% of the marketability component. Finally, the performance component explained 12.89% of the total variation with three statements recording 0.5 threshold factor loadings.

Table 9: Factor Loadings of BSFL Perception Statements after Varimax Rotation

	Rotated	**Components**	
Perception statements	**Acceptability**	**Marketability**	**Performance**
BSFL is acceptable in my religion	**0.765**	0.114	-0.248
BSFL is acceptable in my culture	**0.617**	-0.016	0.311
BSFL will lead to affordable chicken product price	**0.626**	0.045	0.029
BSFL will result in affordable chicken feed ingredient	**0.597**	-0.109	0.137
BSFL-Based feed should have special features for easy identification by farmers	**0.559**	-0.301	0.200
Insect production can contribute to increase the income of families in low-income areas	**0.770**	0.157	0.180
I am willing to use BSFL once it is commercially available	0.144	**0.781**	0.078
The level of knowledge influences the willingness to purchase insect feed	-0.185	**0.820**	-0.092
Buyers and consumers of chicken products will buy products that were fed on BSFL	0.020	**0.906**	-0.081
Chicken fed on BSFL will grow faster	0.338	0.181	**0.809**
BSFL has high protein content	0.312	-0.051	**0.815**

BSFL can be fed to all livestock	-0.254	-0.250	**0.561**
Eigen values	3.355	2.396	1.451
Variance explained (%)	27.960	19.958	12.089
Cumulative variance explained (%)	27.960	47.918	60.008
Cronbach's alpha	0.851	0.546	0.726

Note: Cronbach's alpha = 0.851; Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy = 0.687; Bartlett's test of sphericity: Chi-square (df) = 1100.556 (66) p-value< 0.001.

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization

4.2.7 Multiple Regression Estimates of the Factors Influencing Smallholder Chicken Farmers' Perception on BSFL-Based feed

The adjusted R-squared which is a measure of goodness of fit ranges between 3.15% and 28.56%. The values of the R-squared recorded from this study are low but within the range of similar studies (Asai *et al*., 2014; Okello *et al*., 2021). Also, Greene (2012) asserted that it is common to record low goodness of fit when using a regression analysis with cross-sectional data. The overall findings indicate that; number of contact with agricultural extension services, participation in off farm activities, group membership, education level and awareness of the attributes of BSFL significantly influenced smallholder chicken farmers' perception.

This study estimated four multiple regression equations. The dependent variables of the four equations are perception indices computed using the PCA method. The indices comprise of three individual BSFL-Based feed component indices derived from the factor scores of three key BSFL perception components (performance, acceptability, and marketability) and a composite index of the three individual BSFL-Based feed components obtained through aggregation of the three perception indices. Montgomery *et al*. (2021), specified the OLS as a linear equation of the parameters as follows:

$$Yi = Xk\beta x + \varepsilon \qquad (10)$$

where *Yi* is the n*th* factor score, β*k* denotes the vector of the parameters to be estimated; X*k* is the vector of the farmer specific characteristics such as: age, gender, education level, monthly income, awareness of incorporation of insects in animal feeds, participation in off farm activities, number of contacts with extension officers, and membership in poultry groups, while ε captures the statistical random term that accounts for measurement error.

Table 10 : Multiple Regression Estimates of the Factors Influencing Smallholder Chicken Farmers' Perception on Black Soldier Fly Larvae-Based Feed

Explanatory variable	**Composite perception index**	**Acceptability index**	**Marketability index**	**Performance index**
Age of the respondent	-0. 038 (0.102)	0.033 (0.097)	0.158 (0.226)	0. 010 (0. 190)
Gender of the respondent	-0.008 (0.014)	-0. 005 (0.013)	-0.005 (0.030)	0. 014 (0.025)
Education level	0. 004 (0.002)**	-0.004 (0.002)**	0.015 (0.004)***	0. 001 (0.003)
Awareness of BSFL attributes	0.221 (0.066)***	0.519 (0.063)***	0.129 (0.146)	0. 0149 (0.123)
Number of contact with agricultural extension officers	0.635 (0.166)***	0.547(0.158) ***	0. 627 (0.368) *	0.731 (0.309)**
Membership in poultry groups	0.116 (0.035)***	-0.132 (0.033)***	0.594 (0.077)***	0.114 (0.065)*
Participation in off farm activities	0. 065 (0.053)	-0.044 (0.051)	0.446 (0.118)***	0.295 (0.099)***

Constant	2.839(0.219)	3.511 (0.209)	1.547 (0. 485)	3.461 (0.409)
Adjusted R-squared	0.161	0.286	0.242	0.032
Observations	245			

Note: *** P≤ 0.01 significance level, ** P ≤ 0.05 significance level, * P ≤ 0.1 significance level and standard errors are presented in parentheses.

The findings indicate that awareness of BSFL by smallholder chicken farmers positively and significantly influenced perception at 1% significance level. This finding held true for acceptability index at 1% significant level. This is in line with the expectations of the study that chicken farmers' prior knowledge would affect how they perceive the BSFL-Based feed. Smallholder chicken farmers who were aware of the BSFL attributes were more likely to have a favourable perception of BSFL as a feed ingredient for their chicken than their counterparts. This finding could be attributed to the fact that perception is based on exposure and knowledge. The results tally with Oladele and Fawole (2017) who found that farmers' awareness of agricultural technologies significantly influenced their perception of the relevance of technologies in agriculture.

The coefficient for age of the respondent was not statistically significant, thus it did not have an influence on how chicken farmers perceived insect-based feed as an alternative protein source for their chicken for all the perception indices. Although Kabir (2015), revealed that age was a significant factor that negatively influenced farmers' attitude and perception of ICT based farming in Mymensing Sadar Upazila. On the other hand, Tang *et al.* (2013) asserted that age of the farmers significantly and positively influenced how they perceived droughts and water scarcity in Guanzhong Plain, arguing that older farmers tend to have experienced more droughts and recall more on how address it than their counterparts. Regarding gender, the coefficient was not significant in influencing how chicken farmers perceived insect based feed as an alternative protein.

On the other hand, the coefficient for the level of education was positive and significant at 5% level for the overall composite perception index; also, the coefficient was statistically significant for acceptability and marketability indices. The more educated the farmers are, the more likelihood that they could have a favourable perception of BSFL as an alternative protein for their chicken. This implies that educated chicken farmers could have the knowledge and better access to information, and confidence to understand the benefits associated with the use of BSFL. Marescotti *et al*. (2021) found out that education level was significant in influencing how livestock farmers perceived technologies and innovations for breeding in Switzerland. The results also corroborates with Saha *et al*. (2018) who argued that educated farmers were more aware and they very keen on agroforestry practices as compared to their counterparts.

The number of contacts with agricultural extension officers significantly and positively influenced how chicken farmers perceived BSFL at 1% level for the overall composite perception index. The coefficient was also significant for acceptability, marketability and performance indices. This could be attributed to the fact that receiving training from service providers acts as a network for disseminating information hence the likelihood of favourable perception of BSFL. Fosu-Mensah *et al*. (2012) indicated that access to extension services is an important factor in influencing farmers' perception and adoption of climate change among farmers. Also, Denkyirah *et al*. (2017) revealed that cocoa farmers' perception of long-term changes in climate was significantly influenced by access to extension services. The findings corroborates Sertse *et al*. (2021) who found out that accessing agricultural advisory services positively and significantly influenced how households perceived adaptation strategies to climate change risks.

Regarding membership in poultry groups, the coefficient was positive and statistically significant. The respondents' tendency to view the incorporation of insects in their feed formulation process on the farm favorably increased for members of poultry groups compared to their counterparts for the composite perception index, performance, acceptability, and marketability indices this could be attributed to the positive effect of information sharing and peer learning among the chicken farmers during their group meeting sessions. The findings corroborates with Okello *et al*. (2021) who revealed that chicken farmers belonging to farmer groups were more likely to have a favorable perception of insect-based feed compared to their counterparts.

Regarding participation in off farm activities, the coefficient was found to be statistically significant and positive at 1% level for marketability index as well as performance index. This implies that the chicken farmers participating in off-farm activities were more likely to have a favourable perception of BSFL as an alternative protein source than their counterparts. It could be that chicken farmers participating in off-farm activities make enough income that they possibly use to complement agricultural production activities. Okello *et al*. (2021) argued that farmers with off farm income were more likely to have a favourable perception towards commercial insect based feed for their livestock. Also the findings corroborates with Martey *et al*. (2014) who found a positive relationship between farmers perception and agricultural programmes which they attributed to the inputs and new farming techniques that farmers were introduced to. Also, Kassie (2018) asserted that involvement in off farm income generating activities had a positive influence on how farmers' perceived agroforestry practises in Ethiopia.

4.3. Factors Influencing the Adoption of Black Soldier Fly Larvae Based feed

4.3.1 Statistical tests for Binary Probit Regression Model

4.3.2. Variance Inflation Factor test for Continuous Variables in the Binary Probit Regression Model

Cross sectional data from survey are mainly associated with the problem of multi-collinearity. Variance Inflation Factor (VIF) was performed to ensure that the data was reliable and suitable for the model. VIF was performed to test for the presence of high interdependencies among the continuous variables. Usually VIF is used to determine the precision of estimation in a regression model by expressing the extent to which the interdependence among the explanatory variables degrades the precision of the model estimate (Kavzoglu *et al*., 2014). The VIF values recorded ranges between 1.02 and 1.31 which is below the minimum acceptable threshold of 5 indicating that there was a low association between the continuous variables. By the rule of thumb, VIF values above 5 in a model indicate the presence of high interdependence among the independent variables of a regression model (Arabameri *et al*., 2019).

Table 11: Variance Inflation Factor test for Continuous Variables in the Binary Probit Regression Model

Variable	VIF	1/VIF
Age in years	1.11	0.897
Monthly income in Kes	1.02	0.985
Years in chicken farming	1.08	0.929
Number of chicken kept	1.06	0.944
Household size	1.10	0.906
Contacts with extension officers	1.31	0.765
Amount of credit borrowed or amount received as grants	1.04	0.962
Distance to the market in kms	1.22	0.819
Mean VIF	1.12	

4.3.3. Pairwise Correlation for Categorical Variables in the Binary Probit Regression Model

Diametrically, a pair-wise correlation was conducted for the categorical variables to test for multi-collinearity and the results as presented in Table 11 indicated that the categorical variables were also not highly interdepended. By the rule of thumb, values above 0.7 in a pair-wise correlation indicate higher levels of correlation among the categorical variables used in predicting a regression (Heit *et al*., 2017; Vu *et al*., 2015). Premised on the results presented in Table 12, the proposed explanatory variables exhibited values lower than the threshold of 0.7, indicating absence of any problem involving two or more covariates used in the model. Therefore, all the potential predictor variables were retained for the execution of the binary probit regression model to determine the specific factors that influenced farmers' adoption of black soldier fly larvae as an alternative protein source.

Table 12: Pairwise Correlation for Categorical Variables in Binary Probit Model

Variable	Education	Off-farm activities	Occupation	Gender	Membership	Awareness of BSFL	Reasons for rearing
Education	1.000						
Off-farm activities	0.1429	1.000					
Occupation	0.0556	-0.0024	1.000				
Gender	-0.0109	-0.2239	0.2089	1.000			
Membership - groups	0.0504	0.0060	0.0837	0.1746	1.000		
Awareness of BSFL	-0.0319	-0.0267	0.1126	0.2212	0.5156	1.000	

Reasons for rearing	-0.0507	0.0254	0.0220	0.1852	0.2373	0.1586	1.000

4.3.4 Factors Influencing the Adoption of BSFL-Based feed as an Alternative Protein Source among Smallholder Chicken Farmers in Uasin Gishu County.

Maximum likelihood estimates of probit regression model results used to determine factors influencing the adoption of BSFL as an alternative protein source among smallholder chicken farmers. The log likelihood for the fitted model of -117.71 and a p-value of 0.000 obtained indicate that at least one of the regression coefficients was not equal to zero, it also indicates that all the parameters were significant, a confirmation that the model had a good fit. Pseudo R-squared (Pseudo R^2) was 0.274 indicating a strong explanatory power of the model as it is above the minimum statistical threshold value of 0.2 as poised by Greene and Hensher (2010) and Srisopaporn *et al*. (2015). Variables; age, education level, monthly income, amount of credit received as loans or grants, awareness of the attributes of black soldier fly larvae meal, number of contact with agricultural extension officers, participation in off farm activities and membership in poultry groups were statistically significant in influencing the decision to use black soldier fly larvae as an alternative protein source among the smallholder chicken farmers.

Table 13: Factors Influencing the Adoption of Black Soldier Fly Larvae as an Alternative Protein Source

Variable	**Coefficient**	**Standard error**	**p>z**
Age of the respondent in years	-1.626**	0.660	0.014
Occupation	0.003	0.115	0.988
Education level	0.449**	0.227	0.048
Household size	0.028	0.052	0.582

Monthly income in Kes	0.393***	0.130	0.002
Membership in poultry groups	0.268*	0.148	0.071
Years in farming	0.443	0.416	0.289
Awareness of BSFL attributes	1.906***	0.564	0.001
Amount of credit accessed in Kes	0.626***	0.232	0.007
Number of chicken kept	0.014	0.019	0.597
Number of contacts with agricultural officers	0.749**	0.321	0.019
Participation in off farm activities	-0.561***	0. 147	0.000
Distance to the market in kms	-0.079	0.283	0.780

Number of observations = 245

LR chi^2 (13) = 88.87

Pseudo R2 = 0.274

Log likelihood = -117.71

Prob > chi2 = 0.000

Note: *** P≤ 0.01, ** P ≤ 0.5, * P ≤ 0.1 significance level.

The age of the decision maker with regard to buying for chicken and likelihood to use BSFL on chicken as a protein source was negative and significant at 5% level. This implies that as the age of the chicken farmer increases, the likelihood to use BSFL on their flock would reduce. This could suggest that as farmers grow old, they may be reluctant to uptake BSFL-Based feed and they could have a tendency of being conservative and risk-averse in nature compared with younger farmers. Also, older people are likely to be more resistant to change and innovation with little interest in investing in new agricultural technologies introduced to them compared to their counterparts. These results tally with those of Kisiangani *et al*. (2019) on adoption of agricultural technologies who argued that farmer's age negatively affected their likelihood to adopt technologies introduced by students on attachment programme in Nakuru and Baringo Counties in Kenya. Also, Zulfiqar and Thapa (2018) on adoption of "*better cotton*" in Thailand argued that an increase in the age of the farmer confines the time frame through which a farmer can benefit from adoption resulting into risk-evasiveness. However, Ng'ombe *et al*. (2014) indicated a positive correlation between age of the household head and adoption of conservation farming practices in Zambia.

Education level was positive and significant in influencing the likelihood of chicken farmers to use BSFL on their chicken at 5% level. This implies that farmers who were more educated had higher likelihood to adopt insects as an alternative protein source. Farmers with high level of education are more rational, open minded and with capabilities of assessing the benefits associated with BSFL. As a result, introduction of new technologies to such farmers becomes easy, thus influencing the adoption positively. These results are consistent with Ghimire *et al.* (2015); Paltasingh *et al*. (2017) who argued that more years of schooling creates conducive environment for adoption of new technologies among farmers.

Farmers' participation in off farm activities influenced the likelihood of adopting insect based feed significantly and negatively. This implies that the more the farmers participated in off farm income generating activities, the more likely they would tend to devote less time to farm activities if they earn more income from engaging in off farm activities, hence unlikelihood of using insect based feed on their chicken. The findings are consistent with Suvedi *et al*. (2017) who asserted that having a family member participating in off-farm work may reduce the amount of available time and labor of those farm households for agricultural work. On the other hand, the results are inconsistent with Hugos *et al*. (2018) who argued that engagement in off-farm activities had a positive and significant influence on the adoption of upland rice. The money from off-farm activities would be used for purchasing of inputs that enable them to adopt rice technology.

The effect of farmers' level of monthly income on the likelihood of adopting BSFL among smallholder chicken farmers was positive and significant at 1%. This therefore implies that as chicken farmers level of income increased, their likelihood to buy BSFL for their chicken increased as compared to those who earn lower income. This finding could be expected because an increase in income increases the consumers' purchasing power *ceteris paribus*. Similar findings were reported by Pambo *et al*. (2015) who argued that as consumers incomes increased, their willingness to pay for fortified sugar increased among consumers in western Kenya. Also Shallo *et al*. (2020) argued that level of income was significantly and positive in influencing the adoption of biogas technology among residents in Southern Ethiopia.

Chicken farmer's awareness and prior knowledge of the attributes of BSFL positively and significantly affected the likelihood of chicken farmers to use BSFL as an alternative protein source at 1% level. Implying that the more aware and knowledgeable the farmers were about the attributes of the BSFL, the more likely they were to use it on their chicken. The low adoption levels of BSFL (38 %) by smallholder chicken farmers may be attributed to inadequate information availed to the farmers by the respective agricultural extension officers. These results tally with the findings of Abdullahi *et al*. (2021) who found out that knowledge of smart agricultural practises, attitudes and perceived importance of the technologies significantly influenced the adoption of smart agriculture technologies. Also, Zakaria *et al*. (2020) asserted that farmers' adoption of climate-smart agricultural technologies was positively influenced by how they perceived the climate smart technologies introduced to them. On the other hand, Asare-

Numah *et al*. (2022) found out that farmers' knowhow and perception significantly influenced the adoption of technologies and innovations among mango farmers in Ghana.

Amount of credit borrowed influenced the probability of adopting BSFL positively and significantly at 1%. This implies that as the amount of credit borrowed or received as grants increased, their likelihood to use BSFL on their flock increased positively. This could be attributed to the positive effect associated with the risk taking behaviour of farmers who could easily uptake the technologies under the Kenya climate smart agriculture project areas of implementation that worked with farmers in promoting technologies, innovations and management practises under the chicken value chain. These results are consistent with the findings of Gido *et al*. (2015) who argued that credit access enhances the farmers' purchasing power and ability to meet the transaction cost involved in agricultural production activities. These results also corroborates with the findings by Mwangi and Kariuki (2015) who argued that access to credit promotes the adoption of risky agricultural technologies by addressing liquidity constraints faced by farmers and boosting their risk-bearing ability. However, the results are inconsistent with Diiro and Sam (2015), who found a negative relationship between receipt of credit and adoption of improved seeds which they attributed to the risk evasive nature of farmers and high cost of servicing debt capital.

With regard to number of contact with agricultural extension officers offering agricultural advisory services to farmers, the relationship was positive and significant at 5% level. Accessing agricultural advice through trainings and farm demonstrations exposes farmers to a number of technologies that they could use to improve their agricultural productivity. This finding indicates that chicken farmers who were exposed to agricultural trainings and information had a higher probability of increasing their uptake of black soldier fly larvae on their chicken relative to those with no exposure. This could probably imply that agricultural advice equips farmers with appropriate information enabling them to practically observe the technologies introduced to them through farm visits as well as demonstrations by the service providers and agricultural officers. The findings tally with those of Jenrola and Gaspart (2021) who argued that holding other factors constant, households with access to agricultural advisory services are more likely to adopt new agricultural technologies. Also, Mentire and Gecho (2017) found out that there was a positive and significant relationship between agricultural advisory services and the adoption of wheat row planting technology in Southern Ethiopia.

The coefficient for membership in poultry groups had a positive and significant effect on the chicken farmers' likelihood to uptake insects as an alternative protein source for chicken at 10% level, depicting that belonging to social groups increases the probability of using insects as an alternative protein this could be as a result of sharing information and skills acquired through farmers interactions during the group sessions when they come together to jointly buy feeds and other inputs or when collectively marketing their chicken and chicken products. The findings contradict with Mwangi and Kariuki (2015) who revealed that social groups may have a negative impact on technology adoption in the event of free-riding behaviour by members. On the other hand, Ahmed *et al*. (2022) asserted that members of agricultural groups are likely to interact with their local farming community and agricultural experts who end up sharing knowledge, therefore uptake of technology became easier among farmers in Bangladesh.

4.4. Gross Margin Differences between Black Soldier Fly Larvae and Conventional Protein Sources

To account for the costs and benefits for smallholder chicken farmers, gross margin was considered. Gross margin refers to the total income derived from the chicken production venture less the variable costs incurred in the enterprise as shown by the formula below.

$$GM = \sum P_y Y - \sum P_x X \quad (10)$$

Gross margin analysis enables producers to evaluate their existing enterprise performance, and for those who are contemplating investing in a new enterprise, it provides a guide to estimating the viability of the contemplated investment. Protein component ingredients used by smallholder chicken farmers include black soldier fly larvae and fishmeal. The value for own labour was included in the costs as well as treatment cost, cost of buying antibiotics and vaccines and hired labour was classified as variable costs in the chicken enterprise. The eggs and chicken consumed at the household, slaughtered for visitors or gifted out to friends were all considered in the study as part of the revenue for the household.

The results revealed that an average of 47.5 kgs of fishmeal protein was bought, while 35.8 kgs of BSFL were purchased by the smallholder chicken farmers for the last production season for own farm chicken feed formulation, the difference was statistically significant at 1% level. The mean expenditure on protein component was Kes. 5659/= for fishmeal and Kes. 3580/= for BSFL which was statistically significant at 1% significance level, with dried BSFL selling at Kes. 100 per kilogram and kes.120 per kilogram of grounded fishmeal. The average total variable cost was Kes. 24203/= for fishmeal and Kes. 16669/= for BSFL which was statistically significant at 5% significance level. The average total revenue per smallholder chicken farmer was Kes. 73950/= for fishmeal and Kes. 97645/= for BSFL, whereas, the Gross Margin profit per chicken farmer was Kes. 80978/= and Kes. 49747/= for BSFL and fishmeal respectively.

The value of the gross margin obtained is proxy, this is because the study only focused on the protein component as the only ingredient which is most expensive compared to carbohydrate ingredient which is readily available from farm such as maize products that is cultivated in the study area. Also, fixed costs like depreciation of chicken coop, construction of chicken house and incubators were not included because it varies from one chicken farmer to the other. This concurs with the studies carried out by Mburu *et al*. (2007) and Bawa and Ani (2014) who excluded fixed cost in their studies because it varied from one farm to another. However, gross margins are still useful in assessing enterprise profitability and are widely used in farm management economics (Enting *et al*., 1997; Firth, 2002; Karane, 2016).

The implication of relatively low profit margins earned by smallholder chicken farmers could be attributed to the scale of production since the average number of chicken kept was relatively low, per household. Moreover, the relatively low prices for chicken and eggs and higher total production costs which might have deincentivise chicken farmers; and poor access to market information especially on demand and supply to urban areas further attribute to low profit margins realized by smallholder chicken farmers. Poor access to market information leaves smallholder farmers with an option to sell their produce at low farm gate prices. Therefore, the high opportunity cost of production cannot be distributed over the small number of chicken reared thus giving a low profit margin to the smallholder chicken farmers.

Table 14: Gross Margin Differences between adopters and non-adopters of black soldier fly larvae

	BSFL	**(93)**	**(Conventional)Fishmeal**	**(152)**	
Variable	**Mean**	**SD**	**Mean**	**SD**	***t* Value**
Quantity of protein (kgs)	35.8	9.716	47.5	22.024	-4.519***
Expenditure on protein (Kes)	3580	971	5659	2049	-8.113***
Treatment cost (Kes)	5517	3832	7518	5728	-3.150
Vaccination cost (Kes)	2759	2597	2971	2406	-0.662
Labour cost (Kes)	6807	3712	8055	7944	-1.528
Total variable cost (Kes)	**16669**	**11112**	**24203**	**21127**	**-2.043****
Number of eggs	3564	3034	2838	2754	1.964
Number of hens	92	39	101	29	2.728
Number of cocks	6	12	5	5	1.494
Revenue from eggs (Kes)	57819	62442	41771	45447	2.346
Revenue from hens (Kes)	34618	23710	28047	18016	2.462

Revenue from cocks (Kes)	5208	8434	4132	5270	1.217
Total Revenue (Kes)	**97645**	**44586**	**73950**	**58773**	**1.969****
Gross margin (Kes)	**80978**	**33474**	**49747**	**27606**	**1.583***

Note *, **, *** = significant at 10%, 5% and 1% level, respectively.

However, it should be noted that, the total average gross margins per smallholder chicken farmer could not necessarily reflect a genuine production performance at farm level because the current study only focuses on the protein component which is the most expensive ingredient compared to other ingredients in formulation of chicken feeds at the farm level. These results are consistent with the findings of (Fisher *et al*., 2020; Onsongo *et al*., 2018) also asserted that the inclusion of black soldier fly larvae in chicken feed is suitable for chicken diet when substituted with fishmeal or soybean and cost-effective in comparison with fishmeal and soybean.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The following are the key conclusions of the study according to the objectives.

i. Principal component analysis revealed that the overall perception index, social acceptability, feed performance compared to conventional protein sources, and marketability of chicken products reared on BSFL were the key attributes guiding chicken farmers' buying decisions. Awareness of BSFL attributes, education level, access to agricultural extension services, group membership, and participation in off-farm activities significantly influenced chicken farmers' perceptions of BSFL.
ii. Number of contact with agricultural extension officers and membership in poultry groups were found to significantly influence uptake of black soldier fly larvae among smallholder chicken farmers. These findings underpin the importance of encouraging proper dissemination of agricultural extension services and the need for strengthening chicken farmers groups which could provide pathways for attitude, perception change and knowledge sharing that is key in adoption of new agricultural technologies among smallholder farmers.
iii. The findings reveal that both black soldier-fly larvae users and fishmeal users realise profit from chicken farming. However, utilizing black soldier fly would make chicken farmers realise higher profits compared to fishmeal, although the value of the profit generated from each kind of protein source was proxy because this study only considered protein as the only feed ingredient.

5.2. Recommendations and Policy Implications

i. Interventions such as trainings and farm demonstrations would increase chicken farmers' technical know-how on improving the productivity of chicken reared on BSFL. Accessing agricultural extension services is essential in reducing chicken farmers' uncertainties of accepting BSFL as an alternative protein source.

ii. There is need to have a stakeholder engagement platform for the poultry feed industry sector and policy makers to communicate relevant information regarding the incorporation of BSFL as high-quality protein ingredients in animal feeds to chicken farmers, particularly through increased awareness creation by farm demonstrations and trainings to make farmers aware of the attributes of the BSFL as they feed it to their chicken, as well as increase farmers' knowledge and exposure as lack of it is a major drawback to introducing new technologies and innovations to farmers.

iii. The county extension officers and private extension agents should consider access to agricultural extension services and participation in off-farm income generating activities of smallholder chicken farmers when seeking introduction of new technologies and innovations in the agricultural sector.

iv. Public-private partnerships with resource-endowed farmers and farmer groups are recommended to improve knowledge sharing on new technologies in the agricultural sector.

v. There is need to have a stakeholder engagement platform for the poultry feed industry sector and policy makers to communicate relevant information regarding the incorporation of BSFL as high-quality protein ingredients in animal feeds to chicken farmers, particularly through increased awareness creation by farm demonstrations and trainings to make farmers aware of the attributes of the BSFL as they feed it to their chicken, as well as increase farmers' knowledge and exposure as lack of it is a major drawback to introducing new technologies and innovations to farmers.

vi. Lastly, policy interventions by county government in Uasin Gishu through the livestock officers ought to be geared towards increasing chicken farmers' technical knowhow and ability to evaluate the performance of different chicken breeds at different ages reared on BSFL through technical trainings at group level to capitalize on peer learning among the farmers.

5.3. Suggestions for Further Research

Although this study only covered fishmeal as the only conventional protein source, it is also equally important for future researchers to dwell on other conventional protein sources whether plant-based protein or animal-based protein such as canola, soybean and sunflower in comparison to black soldier fly larvae. The study also concentrated only on smallholder chicken farmers utilizing either fishmeal or black soldier fly larvae. Future studies may consider utilization of insect based feed among other livestock like pigs and fish while exploring coverage of more counties to improve the applicability of the results since the current study only focused on Uasin Gishu County, one out of forty-seven Counties.

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APPENDICES

Appendix A: Research Questionnaire

Farmers Survey Questionnaire

Questionnaire No……………………….

Dear sir/madam,

HALLO, my name is ___________________and I am part of a team from Egerton University, who are studying the ***perception of smallholder chicken farmers on black soldier fly larvae-based feed as an alternative protein source in Uasin Gishu County*****.** Your participation in answering these questions is highly appreciated. Your responses will be **COMPLETELY CONFIDENTIAL** and used solely for research purposes together with other 246 households. If you indicate your voluntary consent by participating in this interview, may we begin? Your participation will be greatly appreciated. If you have any questions or comments about this survey, you may contact survey supervisor through the following address: **Gladys Jepchirchir Koech Department of Agricultural Economics and Agribusiness Management, Egerton University, P.O. Box 536, Egerton. Cell phone: 0714850254.** Email address: gladyskoech29@yahoo.com

Sub-County………………………………………….. Ward……..………………………………

Sub-location…………………………………...Date……...…………………………………...…...

1. Name of enumerator …………………...Date………..……
2. Code number of the respondent………………………………

SECTION A: INFORMATION ON FARMERS SOCIOECONOMIC CHARACTERISTICS

Please tick (√) the appropriate choice

1. What is your age in complete years?.......................
2. Gender:1=Female [ ] 0=Male [ ]
3. What is your level of education? 1= no formal education 2= primary education, 3=secondary education, 4=tertiary education

4. How many household members live permanently in the compound?..................
5. What is your occupation?

   1=Farmer [ ]

   2=Civil servant [ ]

   3=Self-employed [ ]

   4=others specify…………………………………..
6. Are you involved in any other activities that are on-farm? 1=Yes [ ] 0=No [ ]
7. Are you involved in any other activities that are not on-farm? 1=Yes [ ] 0=No [ ]
8. What is your monthly expenditure (income)? Kes………………………………………
9. How many years have you been practising chicken farming?....................

SECTION B: FARMER'S INSTITUTIONAL CHARACTERISTICS

1. Are you a member of any poultry group? 1=yes [ ] 0=No [ ]

   If no, why?
2. Indicate the number of times you get agricultural advisory service from the ward agricultural officers or any other agricultural service providers?
3. What is your main reason of rearing chicken?

   0=Own consumption [ ] , 1=Commercial [ ]
4. How much credit did you borrow for chicken production in Kes……
5. What are your main sources of credit?

   1= Commercial banks / Microfinance institutions [ ]

   2=SACCO [ ]

   3=Informal lenders/chama [ ] Farmer group

   4=Grants [ ]
6. How many chickens did you keep the last production season?.........
7. Are you able to assess the performance of insect based feed in comparison with fishmeal(omena) and insects 0=no, 1=yes.
8. Are chicken products(meat and eggs) marketable when buyers know they were fed with insects?1= yes, 0= no
9. What is the distance to the nearest marketplace?...
10. What are the prices of inputs and outputs?

Inputs in Kes	Quantity	Price	Outputs in Kes	Quantity	Price
Feed ingredients in (Kgs)			Hen		
BSFL(kgs)					
Soy bean(kgs)					
Fish meal (kgs)					
Treatment			Cock		
Vaccines			Eggs		
Labour					

SECTION C: BSFL ATTRIBUTES

On a scale of 1 to 5 (1- Strongly disagree, 2- disagree, 3-neutral, 4- agree, 5- strongly agree), please indicate in what way you agree with the following statements relevant to nutritional value of BSFL, acceptability of BSFL-Based feed, its multiple use, performance and marketability of chicken products fed on insect based feeds.

Marketability of products

Marketability of products	**1**	**2**	**3**	**4**	**5**
The consumption of insects and derived foods depends on availability					
I'm afraid insect-based foods have an unpleasant taste					
I think feeding chicken with insects is not suitable for our diet					
BSFL-Based feed should have special features for easy identification by farmers					
Buyers and consumers of chicken products will buy products that were fed on BSFL					

Acceptability of BSFL-Based feed

Acceptability	1	2	3	4	5
BSFL is acceptable in my culture					
BSFL is acceptable in my religion					
I am willing to use BSFL once it is commercially available					
Industrially processed insect products are hygienic and safe					
There are appropriate regulations to guarantee the food safety of edible insects					
The level of knowledge influences the willingness to purchase insect feed					
Insect production can contribute to increase the income of families in low-income areas					
Insects are a possibility for responding to the growing world demand for protein					
I think insect-based foods have poor hygiene					
The idea of feeding chicken with insects causes disgust/repulsion					

Performance of BSFL-Based feed compared to conventional feeds

Perception statements	1	2	3	4	5
Insects efficiently convert organic matter into protein					
Insects are a good source of energy for chicken					
Insects have high protein content					
Insects contain group B vitamins					
BSFL will lead to improved chicken products(chicken meat and					

eggs)

Chicken fed on BSFL will grow faster

SECTION E: ADOPTION OF BSFL-BASED FEEDS

1. Are you aware of BSFL-Based feed? 0=No[ ], 1=Yes [   ]

   If yes have you adopted it?...............................

   If no, what are the reasons?

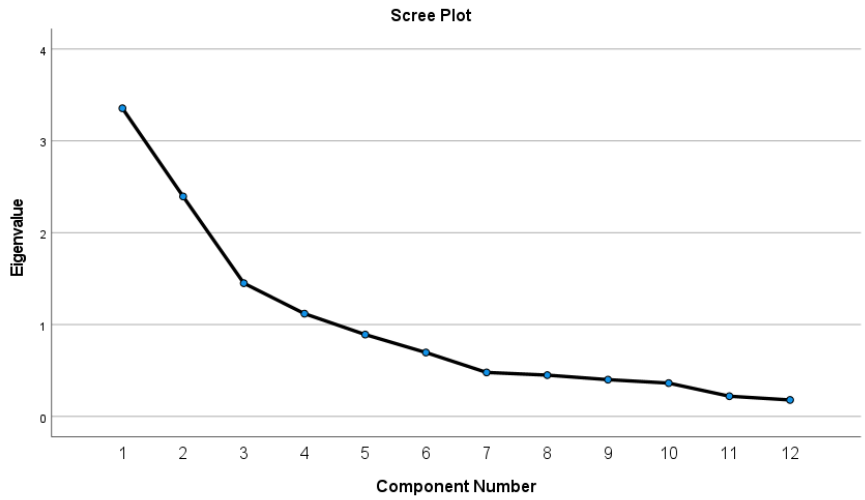
   Lack of information 1

   Not available 2

   Others specify

THANK YOU FOR YOUR TIME AND COOPERATION.

Appendix B: Scree Plot



Appendix C: Test for Sampling Adequacy

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.687
Bartlett's Test of Sphericity	Approx. Chi-Square	1100.556
	df	66
	Sig.	<.001

Descriptive statistics for perception indices

Descriptive Statistics

	Mean		Std. Deviation	Variance
	Statistic	Std. Error	Statistic	Statistic
composite=Acceptabilityp +marketabilityp+performancep)/3	3.9789	.09726	1.40667	.182
Acceptabilityp=(religion + culture + productprice + affordablefeed + identification + lowincome) / 6	4.0878	.02813	.86200	.194
marketabilityp= (buyersandconsumers + knowlwdgelevel + commerciallyavailable) / 3	4.0585	.06347	.99348	.987
performancep= (fastergrowth + highprotein + livestock) / 3	3.7905	.04729	.74021	.548

Appendix D: Descriptive Statistics for Perception Statements

Descriptive Statistics

	Minimum	Maximum	Mean	Std. Deviation
Chicken fed on BSFL will grow faster	2	5	3.66	.715
BSFL can be fed to all livestock	1	5	3.71	1.361
BSFL will result in affordable chicken feed ingredient	1	5	3.89	.956
Insect production can contribute to increase the income of families in low-income areas	2	5	3.92	.407
Buyers and consumers of chicken products will buy products that were fed on BSFL	1	5	3.98	1.266
BSFL has high protein content	2	5	4.00	.921
The level of knowledge influences the willingness to purchase insect feed	1	5	4.06	1.156
BSFL is acceptable in my religion	2	5	4.06	.621
BSFL is acceptable in my culture	2	5	4.07	.568
BSFL will lead to affordable chicken product price	1	5	4.10	.691
I am willing to use BSFL once it is commercially available	1	5	4.13	1.080
BSFL-Based feed should have special features for easy identification by farmers	2	5	4.49	.739

Appendix E: Variance Inflation Factor for Continuous Variables

. vif

Variable	VIF	1/VIF
Agricultur~e	1.31	0.765956
Dis~o_market	1.22	0.819112
AgeHH	1.11	0.897086
HouseHold_~e	1.10	0.906043
Years_farm~n	1.08	0.929064
No_ofchicken	1.06	0.943742
access_cre~t	1.04	0.962372
Monthly_In~e	1.02	0.985193
Mean VIF	1.12	

Appendix F: Pairwise Correlation for Categorical Variables

```
. cor Education_level Offfarm_Activities Occupation Gender_Resp Membership_poultry Areyouaw
> areofBSFLBasedfeed Reason_fr_Chickn_Farming
(obs=245)
```

	Educat~l	Offfar~s	Occupa~n	Gender~p	M~poul~y	Areyou~d	Reason~g
Education_~l	1.0000						
Offfarm_Ac~s	0.1429	1.0000					
Occupation	0.0556	-0.0024	1.0000				
Gender_Resp	-0.0109	-0.2239	0.2089	1.0000			
Memb~poultry	0.0504	0.0060	0.0837	0.1746	1.0000		
Areyouawar~d	-0.0319	-0.0267	0.1126	0.2212	0.5156	1.0000	
Reason_fr_~g	-0.0507	0.0254	0.0220	0.1852	0.2373	0.1586	1.0000

Appendix G: Communalities

Communalities

	Initial	Extraction
BSFL-Based feed should have special features for easy identification by farmers	1.000	.443
Insect production can contribute to increase the income of families in low-income areas	1.000	.650
BSFL is acceptable in my religion	1.000	.660
I am willing to use BSFL once it is commercially available	1.000	.637
BSFL can be fed to all livestock	1.000	.443
The level of knowledge influences the willingness to purchase insect feed	1.000	.715
Buyers and consumers of chicken products will buy products that were fed on BSFL	1.000	.827
BSFL has high protein content	1.000	.765
Chicken fed on BSFL will grow faster	1.000	.802
BSFL is acceptable in my culture	1.000	.478
BSFL will result in affordable chicken feed ingredient	1.000	.387
BSFL will lead to affordable chicken product price	1.000	.395

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component		
	1	2	3
BSFL-Based feed should have special features for easy identification by farmers	.594	-.259	-.151
Insect production can contribute to increase the income of families in low-income areas	.761	.218	-.155
BSFL is acceptable in my religion	.557	.259	-.532
I am willing to use BSFL once it is commercially available	.145	.762	.187
BSFL can be fed to all livestock	.044	-.387	.539
The level of knowledge influences the willingness to purchase insect feed	-.225	.791	.198
Buyers and consumers of chicken products will buy products that were fed on BSFL	-.041	.898	.135
BSFL has high protein content	.659	-.170	.549
Chicken fed on BSFL will grow faster	.674	.060	.587
BSFL is acceptable in my culture	.691	.003	-.014
BSFL will result in affordable chicken feed ingredient	.594	-.055	-.177
BSFL will lead to affordable chicken product price	.566	.119	-.246

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Appendix H: Rotated Component Matrix

Rotated Component Matrix[a]

	Component		
	1	2	3
BSFL-Based feed should have special features for easy identification by farmers	.559	-.301	.200
Insect production can contribute to increase the income of families in low-income areas	.770	.157	.180
BSFL is acceptable in my religion	.765	.114	-.248
I am willing to use BSFL once it is commercially available	.144	.781	.078
BSFL can be fed to all livestock	-.254	-.250	.561
The level of knowledge influences the willingness to purchase insect feed	-.185	.820	-.092
Buyers and consumers of chicken products will buy products that were fed on BSFL	.020	.906	-.081
BSFL has high protein content	.312	-.051	.815
Chicken fed on BSFL will grow faster	.338	.181	.809
BSFL is acceptable in my culture	.617	-.016	.311
BSFL will result in affordable chicken feed ingredient	.597	-.109	.137
BSFL will lead to affordable chicken product price	.626	.045	.029

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

Appendix I: Total Variance Explained

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.355	27.960	27.960	3.355	27.960	27.960	2.952	24.601	24.601
2	2.395	19.958	47.919	2.395	19.958	47.919	2.343	19.524	44.126
3	1.451	12.089	60.008	1.451	12.089	60.008	1.906	15.882	60.008
4	1.119	9.324	69.332						
5	.892	7.430	76.763						
6	.696	5.801	82.563						
7	.479	3.992	86.556						
8	.450	3.749	90.305						
9	.401	3.338	93.643						
10	.363	3.026	96.668						
11	.220	1.836	98.504						
12	.180	1.496	100.000						

Extraction Method: Principal Component Analysis.

Appendix J: Linear Regression Analysis for Composite Perception Index

```
. regress composite AgeHH Gender_Resp  Education_level Membership_poultry Agricultural_advi
> ce Offfarm_Activities AreyouawareofBSFLBasedfeed
```

Source	SS	df	MS
Model	8.22612076	7	1.17516011
Residual	36.1927001	237	.152711815
Total	44.4188209	244	.182044348

Number of obs	=	245
F(7, 237)	=	7.70
Prob > F	=	0.0000
R-squared	=	0.1852
Adj R-squared	=	0.1611
Root MSE	=	.39078

composite	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AgeHH	-.0382267	.1019648	-0.37	0.708	-.2390998	.1626464
Gender_Resp	-.0078458	.0135963	-0.58	0.564	-.0346309	.0189393
Education_level	.0038709	.0017979	2.15	0.032	.000329	.0074129
Membership_poultry	.1161026	.0349484	3.32	0.001	.0472534	.1849519
Agricultural_advice	.6351797	.166048	3.83	0.000	.3080611	.9622982
Offfarm_Activities	.0649595	.0533246	1.22	0.224	-.0400913	.1700103
AreyouawareofBSFLBased~d	.2212659	.0661424	3.35	0.001	.0909638	.351568
_cons	2.839582	.2191865	12.96	0.000	2.407779	3.271384

Appendix K: Linear Regression Analysis for Acceptability Index

```
. regress Acceptabilityp AgeHH Gender_Resp  Education_level Membership_poultry Agricultural
> _advice Offfarm_Activities AreyouawareofBSFLBasedfeed
```

Source	SS	df	MS			
				Number of obs	=	245
				F(7, 237)	=	14.93
Model	14.479405	7	2.06848643	Prob > F	=	0.0000
Residual	32.8283048	237	.138516054	R-squared	=	0.3061
				Adj R-squared	=	0.2856
Total	47.3077098	244	.193884056	Root MSE	=	.37218

Acceptabilityp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AgeHH	.0330935	.09711	0.34	0.734	-.1582156	.2244026
Gender_Resp	-.0048941	.012949	-0.38	0.706	-.0304039	.0206156
Education_level	-.0036471	.0017123	-2.13	0.034	-.0070203	-.0002738
Membership_poultry	-.1315357	.0332845	-3.95	0.000	-.1971068	-.0659645
Agricultural_advice	.5472575	.1581421	3.46	0.001	.2357138	.8588012
Offfarm_Activities	.0437584	.0507857	0.86	0.390	-.0562907	.1438075
AreyouawareofBSFLBased~d	.5194262	.0629932	8.25	0.000	.3953281	.6435243
_cons	3.511007	.2087505	16.82	0.000	3.099764	3.922251

Appendix L: Linear Regression Analysis for Marketability Index

```
. regress marketabilityp AgeHH Gender_Resp  Education_level Membership_poultry Agricultural
> _advice Offfarm_Activities AreyouawareofBSFLBasedfeed
```

Source	SS	df	MS			
				Number of obs	=	245
				F(7, 237)	=	12.12
Model	63.4971451	7	9.07102072	Prob > F	=	0.0000
Residual	177.330973	237	.748231953	R-squared	=	0.2637
				Adj R-squared	=	0.2419
Total	240.828118	244	.987000483	Root MSE	=	.865

marketabilityp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AgeHH	-.1580097	.2257003	-0.70	0.485	-.6026447	.2866253
Gender_Resp	-.0050883	.0300956	-0.17	0.866	-.0643774	.0542007
Education_level	.014775	.0039797	3.71	0.000	.0069349	.0226151
Membership_poultry	.5939735	.0773588	7.68	0.000	.4415748	.7463721
Agricultural_advice	.6273449	.3675492	1.71	0.089	-.0967359	1.351426
Offfarm_Activities	.4459569	.1180347	3.78	0.000	.2134256	.6784881
AreyouawareofBSFLBased~d	.129517	.1464069	0.88	0.377	-.1589082	.4179422
_cons	1.546715	.4851718	3.19	0.002	.5909152	2.502515

Appendix M: Linear Regression Analysis for Performance Index

```
. regress performancep AgeHH Gender_Resp  Education_level Membership_poultry Agricultural_a
> dvice Offfarm_Activities AreyouawareofBSFLBasedfeed
```

Source	SS	df	MS
Model	7.93212238	7	1.13316034
Residual	125.756767	237	.530619268
Total	133.688889	244	.547905282

Number of obs	=	245
F(7, 237)	=	2.14
Prob > F	=	0.0408
R-squared	=	0.0593
Adj R-squared	=	0.0315
Root MSE	=	.72844

performancep	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
AgeHH	.0102362	.1900665	0.05	0.957	-.3641993	.3846716
Gender_Resp	-.0135549	.0253441	-0.53	0.593	-.0634833	.0363736
Education_level	.0004849	.0033514	0.14	0.885	-.0061174	.0070872
Membership_poultry	-.1141299	.0651453	-1.75	0.081	-.2424677	.0142079
Agricultural_advice	.7309366	.3095201	2.36	0.019	.1211746	1.340699
Offfarm_Activities	-.2948368	.0993993	-2.97	0.003	-.4906557	-.0990179
AreyouawareofBSFLBased~d	.0148546	.123292	0.12	0.904	-.2280337	.2577428
_cons	3.461023	.4085723	8.47	0.000	2.656125	4.26592

Appendix N: Binary Probit Results

```
. probit adoption_BSFL AgeHH Occupation Education_level HouseHold_Size Monthly_Income_farme
> rs Years_farming Membership_Poultry AreyouawareofBSFLBasedfeed access_credit No_ofchicken
>  Agricultural_advice Distance_to_market Offfarm_Activities

Iteration 0:   log likelihood = -162.14671
Iteration 1:   log likelihood = -121.03947
Iteration 2:   log likelihood = -117.83892
Iteration 3:   log likelihood = -117.71527
Iteration 4:   log likelihood = -117.71483
Iteration 5:   log likelihood = -117.71483

Probit regression                               Number of obs     =        245
                                                LR chi2(13)       =      88.86
                                                Prob > chi2       =     0.0000
Log likelihood = -117.71483                     Pseudo R2         =     0.2740
```

adoption_BSFL	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
AgeHH	-1.627167	.6595255	-2.47	0.014	-2.919813	-.3345206
Occupation	.0033498	.1097847	0.03	0.976	-.2118243	.218524
Education_level	.4497557	.2258048	1.99	0.046	.0071865	.8923249
HouseHold_Size	-.0291071	.0500464	-0.58	0.561	-.1271964	.0689821
Monthly_Income_farmers	.3935558	.1301282	3.02	0.002	.1385092	.6486024
Years_farming	.4431296	.4145907	1.07	0.285	-.3694532	1.255712
Membership_Poultry	.2677322	.148055	1.81	0.071	-.0224502	.5579147
AreyouawareofBSFLBased~d	1.905213	.564705	3.37	0.001	.7984114	3.012014
access_credit	.6256312	.231712	2.70	0.007	.171484	1.079778
No_ofchicken	.0010291	.0019522	0.53	0.598	-.0027971	.0048553
Agricultural_advice	.7500576	.3207083	2.34	0.019	.1214808	1.378634
Distance_to_market	-.0789012	.2832237	-0.28	0.781	-.6340095	.476207
Offfarm_Activities	-.5612402	.1475011	-3.80	0.000	-.8503371	-.2721433
_cons	-3.162802	1.887255	-1.68	0.094	-6.861754	.5361487

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Appendix O: Publications

International Journal of Agricultural Economics
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Perception of Smallholder Chicken Farmers on Black Soldier Fly Larvae (BSFL) as a Super Alternative Protein Source for Chicken in Uasin Gishu County, Kenya

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Abstract: This study evaluates the perception of smallholder chicken farmers in the utilization of black soldier fly larvae (BSFL) as an alternative protein source, and its incorporation in livestock feed systems in Kenya, with a specific case of chicken farmers in Uasin Gishu, Kenya. The study employed a survey research design covering 245 smallholder chicken farmers interviewed through a semi-structured questionnaire. Results revealed that 72.5% of the chicken farmers were aware of the benefits of incorporating BSFL in chicken feed. Principal component analysis based on perception indices revealed that social acceptability, feed performance compared to conventional protein sources, and marketability of chicken products reared on BSFL were the key attributes guiding chicken farmers' buying decisions. Awareness of BSFL attributes, education level, access to agricultural extension services, group membership, and participation in off-farm activities significantly influenced chicken farmers' perceptions of BSFL. In conclusion, the study demonstrates that interventions such as training and farm demonstrations would increase chicken farmers' technical know-how on improving the productivity of chicken reared on BSFL. Accessing agricultural extension services is essential in reducing chicken farmers' uncertainties of accepting BSFL and encouraging the uptake of this rapidly growing and emerging technology. This work adds to the current understanding of BSFL-based feeds and creates opportunities for further linkages between chicken farmers, public-private partnerships, policymakers, feed manufacturers, and consumers of chicken products.

Keywords: Black Soldier Fly Larvae-Based Feed, Farmers' Perception, Linear Regression, Principal Component Analysis, Smallholder Chicken Farmers

1. Introduction

Agricultural development is considered one of the most impactful approaches to addressing extreme poverty, promoting shared prosperity, and supporting the projected population growth of 9 billion by 2050 [1]. When compared to other sectors, the agriculture industry has proven to be 2-5 times more effective in boosting incomes for individuals who have limited resources. The sector plays a significant role in driving economic growth. It contributes 4% to the global gross domestic product (GDP) and holds even more weight, accounting for over 25% of the GDP in certain least-developed countries [1].

The livestock sector in Africa accounts for one-third of the global livestock population [2] and approximately 40% of African agricultural GDP, ranging from 12% to 78% in individual countries [3]. The rapid growth in the global population has led to increased demand for foods rich in protein, especially animal-based proteins, thus increasing their production [4]. According to the report from FAO in 2017 [4], one approach to enhancing food production and alleviating poverty in Africa is through the implementation of intensive agricultural practices that aim to increase the competitiveness and profitability of livestock businesses. In Sub-Saharan Africa (SSA), poultry, fish, and pig farming have emerged as the most rapidly expanding agricultural

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