PERFORMANCE AND MEAT QUALITY OF BROILER CHICKEN FED DIETS ENRICHED WITH BLACK SOLDIER FLY (*Hermetia illucens*) LARVAE MEAL

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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To my dear friend, confidant and wife Brender

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To God Almighty be all the glory, great things He has done in my life.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BSFL	Black Soldier Fly Larvae
BW	Body Weight
CF	Crude Fiber
CP	Crude Protein
Df	Degrees of Freedom
DM	Dry Matter
EE	Ether Extract
FCR	Feed Conversion Ratio
g	Gram
GHG	Green House Gas Emission
KeBS	Kenya Bureau of Standards
m.s.	Mean Sum of Square
SBM	Soybean meal
SS	Sum of Square

ABSTRACT

Insects are a common feedstuff for wild birds and scavenging poultry. Prospects of insects inclusion in compounded animal feeds as cheaper alternative protein sources has lately attracted intercontinental attention. Black Soldier Fly larvae (BSFL) meal was used to partially replace soybean meal (SBM) and fish meal (FM) in broiler chicken diets to determine the effect on performance, carcass characteristics, breast meat sensory attributes and the economic implication of their use. The BSFL meal was included at a rate of 0, 5, 10 and 15% to form the Control (C), L1, L2 and L3 diets respectively but remain iso-caloric and iso-nitrogenous. Each treatment included both starter and finisher diet fed during the starter phase (day 7 to day 28) and finisher phase (day 28 to day 49) respectively. The larvae meal replaced 0, 13.3, 26.3 and 45.2% of soybean meal and 0, 14.0, 30.0 and 35.0% of fish meal in starter diets C, L1, L2 and L3 respectively while in the finisher diets C, L1, L2 and L3, the larvae meal replaced 0, 19.0, 46.0 and 64.0% of soybean meal and 0, 0, 25.0 and 43.8% of fish meal respectively. The diets were formulated on a least-cost basis, the price of starter and finisher feed for treatment L3 was lowest (54.50Ksh/Kg and 51.50Ksh/Kg respectively) while the control was highest (61.50Ksh/Kg and 57.40Ksh/Kg respectively). Two hundred and eighty eight (n=288) day old Cobb 500 broiler chicks were obtained from a commercial hatchery and acclimatized for one week before being randomly housed in 48 metallic cages (6 birds per cage), each measuring 750mm by 900mm by 750mm and offered the four dietary treatments (72 birds per treatment) for 42 days. Dietary inclusion of up to 15% BSFL meal in broiler chicken diets had similar effect (p>0.05) to the control on body weight gain (BWG), average daily feed intake (ADFI), feed conversion ratio (FCR) and sensory characteristics of cooked breast meat. Cost of rearing the birds on diet L3 to slaughter age was 14.3% cheaper compared to the control, resulting into the highest Cost Benefit Ratio (p=0.031) and best Return on Investment (p=0.031). The study demonstrated that 45.2% and 64.0% replacement of soybean meal and 35.0% and 43.8% replacement of fish meal with BSFL meal was 11.4% and 10.3% cheaper in broiler starter and finisher diets respectively of 16.0% and 25.0% higher Cost Benefit Ratio and Return on Investment compared to the control. The study also demonstrated that at this replacement rate, no adverse effect on ADFI, BWG, FCR, carcass characteristics and sensory attributes of cooked breast meat was observed. In conclusion, the study demonstrated that BSFL meal can be included in broiler diets to partially replace the more expensive soybean meal and fish meal without affecting the birds performance and taste of broiler chicken breast meat.

CHAPTER ONE: INTRODUCTION

1.1 Background information

World population data on annual estimates released by the United Nations, Department of Economic and Social Affairs in July 2015 (UN, 2015) suggests that the global human population is projected to rise, with most of the growth expected in Africa (Gerland *et al.*, 2014). Kenya adds about one million people to its population annually (KNBS, 2009). Demand for cereal and meat products will increase due to growth in human population coupled with higher purchasing power (Coffey *et al.*, 2016). Food security is therefore endangered due to increased demand by a wealthier, growing population and climate change which is aggravating the situation by its direct negative effect on crop yields (Nelson *et al*., 2009). The fact that soybean meal and fish meal are used as both human food and animal feed ingredients means that, an increase in their prices will obviously impact the price of animal protein. Food and Agricultural Organization estimate a huge increase in animal protein demand (Speedy, 2004) with poultry meat accounting for nearly 50% of this global increase in meat consumption (Rosegrant, 2001).

The rising world human population and consequently increases in prices of feed protein ingredients has caused the animal feed industry to seek alternative protein sources as the traditional ingredients like soybean meal and fishmeal cannot meet the demand (Jarosz, 2009). The fast growing human population among other factors will necessitate the animal feed industry to adjust and re-examine its inputs (Coffey *et al.*, 2016).

The need for alternative cheaper animal feed protein ingredients is a matter that requires urgent consideration. Over 50% of the feed consumed by wild birds is insect based (McHargue, 1917). Insects therefore can be a viable protein ingredient source for avian species.

1.2 Problem statement

To feed the world in 2050, the Food and Agricultural Organization (FAO) estimates that our food production will almost have to double (Veldkamp *et al*., 2012). The International Feed Industry Federation (IFIF) also stated that the production of meat products (poultry and pork) will double. This production however may not be achieved due to the high cost of ingredients among other factors as feeds that represent nearly 70% of the cost of production for poultry. There is need to appraise new sources of feed ingredients and to review the most cost effective resources (Leeson and Summers, 2009).

Manure (from the expected increase in livestock numbers) disposal on the other hand is a serious environmental challenge especially in urban and peri-urban farming systems where commercial poultry are raised. Animal manure and other organic material contribute a large fraction of the solid waste in developing countries (UNEP, 2010). There is therefore need to develop environmental friendly means of waste disposal. Insect species such as Black Soldier Fly, the common house fly and yellow meal worm collectively bio-convert approximately 1.3 billion tones of organic waste per year (Veldkamp *et al*., 2012).

1.3 Justification

High prices of conventional protein ingredients used in poultry feed has resulted into research of alternative cheaper sources (Van Huis *et al*., 2013). Insects are a common diet of wild birds and scavenging chicken (Hwangbo *et al*., 2009).

Insects have a tiny ecological foot print and therefore diminished Green House Gas (GHG) and ammonia emission (Oonincx *et al.*, 2010). Palatability of insect meal by poultry and other animal species has been demonstrated and found that it can replace 25-100% of soybean or fish meal in poultry feeds (Makkar, *et al.*, 2014). Insects can be a good protein source of desirable amino acid profile (Sánchez *et al*., 2014). *Hermetia illucens* larvae for instance has a high Ca:P ratio; 1:0.1 (Newton *et al.,* 2005), 35 - 57% CP (Veldkamp *et al.,* 2012), better or comparable amino acid profile to soybean meal (Tran *et al*., 2015), higher lysine and methionine levels than most plant protein ingredients used in poultry feeds and comparable to that in meat meal (Ravindran *et al.,* 1999).

Black Soldier Fly (*Hermetia illucens*) is a Diptera of the Stratiomyidae family that can grow on a wide range of organic substrates hence efficiently incorporating organic waste into production systems (Diener *et al.,* 2009) thereby reducing environmental pollution. Insects when incorporated into diets can also contribute to animal health. Chitin found in the exoskeleton of insects is a non-toxic, biodegradable linear polymer that has demonstrated complex and size dependent effect on innate and adaptive immune response (Lee *et al*., 2008).

A feasibility study was conducted in the Netherlands in 2012 to explore the application of insect in poultry feed (Veldkamp *et al*., 2012). Though the findings were quite promising, further research was recommended to determine inclusion levels in poultry diets and the functional properties of the feed ingredient.

There is paucity of data on performance of broiler chicken offered insect based diets and the optimal level of inclusion. This informed the current study to determine the effect of insect based broiler chicken diets on performance, carcass characteristics, sensory attributes of the breast meat and overall economic implication.

1.4 Objectives

1.4.1 General Objective

To determine the effects of partially replacing expensive protein feed ingredients; soybean meal (SBM) and fishmeal (FM) with Black Soldier Fly larvae (BSFL) meal in broiler chicken diets on performance, carcass characteristics and economics of production.

1.4.2 Specific objectives

1. To determine the performance of broiler chicken fed on diets containing different levels of BSFL meal as a replacement for SBM and FM.
2. To determine the effect on carcass characteristics of broiler chicken fed on diets that have partially replaced SBM and FM with BSFL meal.
3. To determine the cost implication of partially replacing dietary SBM and FM with BSFL meal on broiler chicken production.

1.5 Hypotheses

1. Black Soldier Fly larvae can partially replace SBM and FM in broiler chicken diets without affecting performance.
2. Inclusion of BSFL meal in broiler chicken diets does not affect carcass characteristics.
3. A higher return on investment (RoI) in broiler production is realized when BSFL meal partially replaces SBM and FM in broiler chicken diets.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of broiler production in Kenya

The 2015 Economic review of agriculture (ERA) in Kenya indicated that broiler production had registered a gradual increase which may be due to rural-urban migration and raised purchasing power by its citizens (MoALF, 2015). The State Department of Livestock in Kenya estimated that by 2014 there were over 3 million broilers up from 2 million in 2013 (MoALF, 2015). The country enjoys diversity in poultry production systems of varied levels of inputs and bio-security measures ranging from free range (backyard) to intensive (Bergevoet and Engelen, 2014). Kenya is not an exception to the fact that increased meat consumption in many developing countries is expected to increase livestock production which will in turn raise the demand for protein rich ingredients for food and feed. This is especially so for poultry (Asche *et al.*, 2013) which, compared to other animal species, consumes most of the compounded feed globally (Coffey *et al.,* 2016).

The poultry industry is however constrained by high cost of feeds, which constitute 60-80% of the production costs (MoLD, 2009). Makkar *et al*., (2014) proposed that feed is the most challenging resource because of the food-feed-fuel competition, ongoing climatic changes and the limited availability of natural resources.

2.2 Poultry feed ingredients

The bulk of ingredients used in poultry feeds are the high energy and high protein concentrates. These two are also the most expensive, accounting for 95% of the total feed cost (Ravindran, 2013). Although most of the energy concentrates are locally available, high protein ingredients such as soybean meal and fishmeal are imported by most developing countries (Ravindran, 2013). Kenya sources the bulk of its protein ingredients requirement such as soybean meal from Europe and India, sunflower and cotton cake from Tanzania and Uganda, and fish from Tanzania (Bergevoet and Engelen, 2014). Kenya imports more than 90% of the soybean utilized in the country as demand far exceeds what is locally produced (Chianu *et al.*, 2014). Despite the fact that soybean cultivation has been practiced for over a century in Kenya, production of this legume has stagnated due to perceptions on its laborious heat treatment, limited nationwide awareness on its nutritional value and inadequate know how on its preparation (Chianu *et al.*, 2014).

2.3 Protein feed ingredients

High protein feed ingredients are either of plant or animal origin. Plant protein ingredients include; soybean meal, canola meal, pea and sunflower meal whereas fishmeal and meat meal are the most common animal proteins. Soybean meal is the most preferred plant protein ingredient in poultry diets worldwide (Ravindran, 2013). Approximately 90% of the entire soybean utilized in Kenya is used as livestock feed, mainly in poultry diets (Chianu *et al.*, 2014).

In an attempt to address availability, high cost and better efficiency of conventional feed ingredients, animal nutritionists are now considering the use of novel protein ingredients such as insects, duckweed (Spiegel *et al.*, 2013) and microbial protein (Kuhad *et al.*, 1997) to partially or totally replace the conventional sources.

2.4 Soybean (*Glycine max*)

Soybean is an oil seed legume whose oil can either be extracted mechanically (oil press) or chemically (solvent extraction) resulting in the byproduct known as soybean cake or soybean meal, respectively. This bean is native in East Asia but its high protein and oil content has given it global cultivation preference (Medic *et al.,* 2014). Soybean is the fourth leading crop produced globally (Asche *et al*., 2013).Three countries in the world (USA, Brazil and Argentina) have a commanding influence over the global soybean meal supply (Ravindran *et al.,* 2014). Although its demand as a protein source in poultry feed is huge, intensive soybean production is facing negative environmental and social implications (Semino *et al*., 2009). Large tracts of arable land are needed for soybean production causing enormous deforestation (Aide *et al.,* 2013) while use of genetically modified seeds in an attempt to increase yield has caused some resistance from organic soybean consumers (Vicenti *et al.,* 2009). The future of soybean production is limited since with increased demand there is no increase in land required to grow it. Regions where chicken meat and other animal protein production are on the rise need alternatives that will reduce dependency on this legume (Laudadio and Tufarelli, 2010).

2.4.1 Soybean production and processing in Kenya

Demand for soybean and its related by-products in Kenya far exceed local production (Chianu *et al.,* 2014). Processing is done either at industrial or non industrial level with almost all the soybean in the country undergoing the latter (Chianu *et al.,* 2014). Industrial processing almost wholly relies on importation of soybeans (Chianu *et al.,* 2014). Livestock feed industry is the main consumer of soybean by products in Kenya (Chianu *et al.,* 2014).

2.4.2 Nutrient composition of soybean meal

The relatively high CP level, an amino acid profile of high digestibility makes soybean meal the standard against which other protein sources are compared (Leeson and Summers, 2009). Nutritive value of SBM is influenced by cultivar, climate, agronomic practice, soil conditions, processing conditions and extent of dehulling. Planting date, seeding rate and planting row type affects some parameters of soybean proximate composition and mineral levels (Bellaloui *et al.*, 2015).

The feed industry has for a long time presumed that amount of digestible amino acids of SBM per unit CP is constant. However Ravindran *et al.*, (2014) demonstrated that there is significant variation in the nutritive value of SBM from different origins in terms of apparent metabolizable energy and digestible amino acids. They observed for instance significant difference in the CP level of SBM from USA (47.3%) and Argentina (46.9%).

2.4.3 Anti nutritive factors in soybean and their effect on broiler performance

Protease trypsin inhibitors, isoflavones, lectins and oligosaccharides are among the anti-nutritive factors in soybean (Leeson and Summers, 2009). Of all these factors, protein trypsin inhibitors are the most considered when evaluating the nutritive value of soybean. Heating the soybean (during processing) is among other methods used to lower trypsin inhibitor but overcooking could impair the availability of lysine (Leeson and Summers, 2009).

In an attempt to replace soybean meal with 12% raw full fat soybean in broiler diets, Rada *et al.*, (2017) observed an obvious drop in body weight of the birds and also noted that the trypsin activity and pancreas weight grew as the raw full fat soybean was increased in the diet. Growth performance of broilers is improved when fed on cold pressed low trypsin inhibitor soybean meal (derived from the low trypsin inhibitor soybean variety) than cold pressed conventional soybean meal (Hosotani *et al.*, 2016).

2.5 Fish meal

Fish meal is an expensive, finite global resource due to depleting global fisheries (Hardy and Tacon, 2002; Ravindran, 2013). It is a good source of high quality protein, containing 40-50% CP (NRC, 1994; Willis 2003; Van Eys *et al*., 2004) sometimes up to 64.2% (Kirimi *et al.*, 2016). In Kenya, fish meal is either imported or locally produced (Ravindran, 2013). Local fish meal is generally of low quality due to human adulterations (Ravindran, 2013). Due to ineffective local regulatory mechanisms, inorganic compounds such as sand are used to adulterate fish meal (Ravindran, 2013).

Future expansion possibility of fish meal production is limited. The concern on possible pollutants (e.g. dioxin) levels in fishmeal has limited its use (Ravindran, 2013). Increased demand coupled with human animal competition for fish and its by-products (over a third of world total fisheries catch are used in feed industry as fish meal annually) has resulted into increased global fish meal prices (Ogello *et al.*, 2014).

2.6 Novel ingredients used as protein sources in poultry diets

Novel protein sources include but are not limited to insects, duckweed and microbial protein (Spiegel *et al.,* 2013). Demand for high protein feed ingredients from non-conventional sources has continued to rise, particularly in developing countries (Kuhad *et al*., 1997). This rise can be attributed to the fact that costs of poultry feed can greatly be reduced by using insect meal from different sources especially if reared on bio-waste and produced in large scale to replace fish and soybean meal (Khan *et al.,* 2016; Veldkamp *et al.,* 2012).

2.7 Insects as animal feed

Use of insects as protein source for livestock, especially poultry, has been considered (Sun *et al*., 2013; Kenis *et al*., 2014; Makkar *et al*., 2014). Studies on attitudes towards and willingness to accept insect based animal feed are generally favorable (Verbeke *et al*., 2015). Insects as feed stock for livestock (poultry) can be a sustainable cheaper alternative protein ingredient (Van Huis *et al*., 2013).

Black soldier fly (BSF), the common housefly maggot, silk worm and several grasshopper species are viable insects for mass rearing (Anand, 2008). Some like the common housefly maggot have been proposed as poultry feed (Zuidhof *et al.*, 2003). They can convert poultry manure into high protein (61% CP) of desirable amino acids composition (El Boushy, 1991).

Cullere *et al.*, (2016) demonstrated that BSF (*Hermetia illucens)* larvae meal partially replaced conventional soybean meal and soybean oil in the diets of growing broiler quails. They recommended further studies be undertaken to assess the impact of *H. illucens* meal on meat quality, sensory profile and intestinal morphology. Knowledge on the actual feeding value of insect products for poultry is limited.

Pieterse *et al* (2013) studied the effect of including 10% of *Musca domestica* larvae meal in broiler chicken diets on meat quality. They concluded that *Musca domestica* larvae meal inclusion in broiler diets had positive effects on carcass quality and sensory attributes. Mormon cricket can be included in broiler diets up to 30% without any adverse effect (Makkar *et al*., 2014).

2.7.1 Nutrient composition of insects

Insects provide an abundant source of essential nutrients (van Broekhoven *et al*., 2015). Makkar *et al*., (2014) observed that insect meals contained varied protein and fat contents even when processed from similar insect species as a result of rearing them on different substrates. Methionine and calcium levels in insect meal are lower (1.0% and 1.5% respectively) compared to fishmeal (Józefiak *et al*., 2016). Nutrient concentration of insects depends on their life stage and substrate composition on which the insects are reared on (Makkar *et al.*, 2014).

Generally, insect meals CP are comparable to that of soybean meal but slightly lower than that in fish meal (Makkar *et al.*, 2014). Extracting oil (defatting) from insect meals especially those high in oil is expected to raise the CP content making it comparable to both soybean meal and fish meal (Makkar *et al.*, 2014). To achieve balanced amino acid concentration of insect meals to adequately replace soybean meal in livestock feed, some insect meals are mixed (50:50) or synthetic amino acids added (Makkar *et al.*, 2014).

Chitin is found in the cuticle of insects. Although limited information is available on insect chitin composition, ADF and CF analyses have been used to evaluate the chitin concentration (Józefiak *et al*., 2016). Cuticle removal increases insect meal digestibility in fish (Makkar *et al.*, 2014).

Insects also have antimicrobial peptides (AMPs). These are natural antibiotics that do not lead to bacterial resistance. Yi *et al*, (2014) noted that the largest group of insect AMPs are defensin.

2.7.2 Large scale production of insects

In order to assess the potential of insect use in food and feed, an expert consultative meeting was held in 2012 at the FAO headquarters in Rome. In this forum, large- scale insect rearing was defined as the production of 1 tonne of fresh weight insects per day. Information on rearing conditions and nutrient requirements of insects are a prerequisite for an intensive insect production system. Other important considerations are the adoption of an all-in-all-out system of production and the knowledge of insect diseases as some species can indirectly affect the natural environment (Józefiak *et al*., 2016). Rumpold and Schlüter, (2013) suggest adoption of automated facilities for mass insect production.

Insect species that are viable for mass rearing should have a short life cycle, low disease vulnerability and able to live in high densities within confined space (Van Huis *et al*., 2013). Such insects include *Hermetia illucens* and *Tenebrio molitor* (Yellow mealworm). The consultative meeting held in Rome recommended that countries in the tropics utilize local species and employ small scale (household production) insect farming while those in temperate parts of the world use cosmopolitan species such as (*Acheta domesticus*) house cricket (Van Huis *et al*., 2013). Mono specie insect rearing is discouraged while parental genetic line preservation encouraged due to production system vulnerability (Van Huis *et al*., 2013).

2.7.3 Challenges of insect rearing, insect processing, storage and inclusion in animal feed

In order to sustainably replace soybean and fish meal (expensive conventional protein ingredients) with insect meal, large quantities of insects will have to be consistently and cost effectively reared (Van Huis *et al*., 2013). Investors intending to set up large scale insect rearing plants are faced with a huge challenge of lack or unclear legal framework on mass-rearing and sale of insects for food and feed (Van Huis *et al*., 2013). Some laws like the European Union legislation (Regulation (EC) No. 1069/2009), define insect meal as processed animal protein and therefore the “BSE regulations” prohibit its use in livestock feed.

Insect allergens (contact and inhalant allergens) are a risk factor for personnel in the insect rearing industry (Rumpold and Schlüter 2013). Some insects contain anti-nutrititive factors: *Anaphe* specie of the African silkworm pupae contains heat resistant thiaminase (Rumpold and Schlüter, 2013).

Insect meal shelf life can be prolonged by adding lactic fermented cereal products (Klunder *et al.,* 2012). The most likely pathogen of processed insect meal spoilage is spore forming bacteria while an easy and favorable method of insect meal preservation is drying (Klunder *et al.*, 2012). Processing insects into edible insect products has promoted entomophagy in Kenya (Van Huis, 2013) as it has created some degree of accessibility in a consumer friendly form.

2.8 Black Soldier Fly (BSF)

Black Soldier Fly (*Hermetia illucens*) is a Diptera of the family Stratiomyidae. It is considered a probable feed protein ingredient due to its ability together with other insect species of converting large amounts of organic waste (1.3 billion tonnes annually) into protein-rich biomass (Diener *et al*., 2009; Veldkamp *et al.*, 2012) of good amino acid profile (Maurer *et al.*, 2015).

Plate 2. 1: Black Soldier Fly

Credit to Dave's Garden

2.8.1 Life cycle of Black Soldier Fly

Black soldier fly has a 4 stage life cycle (Egg, Larvae, Pupae and Adult). The adult Black soldier fly is a black wasp-like insect, measuring about 22mm in length (Hawkinson, 2005). It lacks a functional mouthpart and digestive system. The adult has a 7 day life span during which the female looks for a mate to breed while in flight and lay over 500 creamy white eggs adjacent to decaying organic matter. Under optimal conditions the eggs hatch after 4 days into larvae. The larvae are dull white with small projecting heads. It is this stage of the fly that crawls away from the hatching site to feed on the decaying material. The larvae undergo six instars and metamorphosis into the pupae stage. After 14 days the adult emerges.

2.8.2 Entomology and distribution of Black Soldier Fly

Black soldier fly (Plate 2.1) is thought to be a native of the tropic, subtropics and warm temperate zones (Neotropics) and believed to originally occur in the southeastern United States (Marshall *et al.*, 2015). Decades of spread have made this poly-saprophagous fly present in every zoogeographical region. Nyakeri *et al.,* (2016) confirmed the presence of wild BSF in Bondo area of western Kenya. Adult BSF only look for a mate, breed and lay about 500 eggs in crevices near composting waste (Diener *et al.,* 2011). During its adult life the insect doesn’t feed, bite or sting (Park, 2015) therefore the larvae are quite large (220 mg) to store all nutrients necessary to support the adult (Park, 2015; Makkar *et al.,* 2014). The creamy white eggs (Diclaro and Kaufman, 2009) hatch into larvae that instinctly feed on decaying organic matter. The larvae are greedy eaters (each consuming 25 to 500 mg of fresh bio-waste per day) as they need to store enough energy to sustain the entire 7-day adult stage of their life cycle (Park, 2015; Makkar *et al.,* 2014). During the last larval stage the larvae crawl away from the waste into a dark area to pupate. This migratory phenomena is utilized in rearing facilities to self collect (Diener *et al.*, 2011). Although BSF can tolerate weather extremes, they best thrive in temperature ranges of between 29 and 31°C and relative humidity of 50-70% (Makkar *et al.*, 2014).

2.8.2 Nutrient composition of Black Soldier Fly

Black soldier fly larvae (BSFL) are capable of converting large amounts of organic waste into protein-rich biomass (Table 2.1) which can be used to substitute fishmeal in animal feed (Diener *et al*.,2009). BSF larvae fed on organic waste are high in proteins and fat making them ideal as an animal feed ingredient (Lalander *et al*., 2013). The larvae may be used in various forms; live, chopped or dried and ground (Makkar *et al.*, 2014). Chopping is done to facilitate leakage of intracellular fat to produce defatted BSFL meal (Kroeckel *et al.*, 2012). BSFL meal has a desirable amino acid profile with high proportions of lysine (6.0-8.0% of the CP) and methionine (1.7-2.4% of the CP) (Maurer *et al.*, 2015; Tschirner and Simon, 2015) however methionine-cystine and threonine supplementation are recommended because of their low concentration of these amino acids (Makkar *et al.*, 2014).

Black soldier fly (BSF) larvae can have a wide range of ether extract content as a result of using different substrates (Makkar *et al.*, 2014) during larvae production, which is the feeding stage in BSF life cycle. Fatty acid composition of the BSFL is dependent on the fatty acid content of the rearing material. Substrate type greatly impacts nutrient composition and total yield of BSFL (Tschirner and Simon, 2015). Black soldier fly larvae meal has high ash levels (11-28% DM) indicative of the rich calcium (5.0-8.0% DM) and phosphorus (0.6-1.5% DM) content (Makkar *et al.*, 2014).

Table 2. 1: Chemical composition (%) and energy content (kcal/Kg) of Black Soldier Fly larvae on DM basis

	% content	Reference
Dry matter (DM)	95.7	De Marco *et al.*, 2015
	91.3 – 92.6	Spranghers *et al.*, 2016
Crude Protein (CP)	36.9	De Marco *et al.*, 2015
	41.1 - 43.6	Makkar *et al.*, 2014
Ether Extract (EE)	34.3	De Marco *et al.*, 2015
	15.0 – 34.8	Makkar *et al.*, 2014
Energy (Kcal/Kg)	5688	De Marco *et al.*, 2015
	5282	Makkar *et al.*, 2014

2.8.3 Use of Black Soldier Fly (BSF) in livestock feed

Growing chicks had better feed conversion efficiency when BSF larvae were included in their diets to replace soybean meal (Makkar *et al.,* 2014). Although feeding trials show BSF larvae can fully substitute fish meal in fish diets, further studies on rearing substrates, methods of larvae meal processing are necessary as some trials have shown reduced fish performance when fed on BSF larvae based diets (Makkar *et al.,* 2014). The larvae are also a satisfactory protein ingredient with comparable palatability to soybean meal in growing pigs (Makkar *et al.*, 2014), however its high ash content, low methionine-cystine and threonine levels require cuticle removal or amino acid supplementation respectively.

2.8.4 Use of Black Soldier Fly in waste management and other uses

Large fractions of solid waste in developing countries consist of organic material (UNEP, 2010). BSF have been used to compost and sanitize wastes which include fresh manure, animal and vegetable food waste (Park, 2015) which otherwise could have contributed to the annual GHG emissions (UNEP, 2010). BSF can reduce waste biomass by ≥ 50% (Makkar *et al.,* 2014). Bad odors from decomposing organic waste are reduced by BSF larvae which rapidly bio-converts the waste (Van Huis *et al*., 2013). BSF larvae competitively inhibit growth of (a major disease vector) the common house fly (*Musca domestica*) thereby improving the health status of humans and animals (Makkar *et al.,* 2014). It also lowers salmonella specie and viruses in fresh human fecal sludge (Lalander *et al.,* 2015). Biodiesel has become an attractive alternative renewable fuel, but its large scale production has been restricted because of the high cost of feedstock (Atabani *et al*., 2012). A novel BSF biomass feedstock for biodiesel production has been evaluated and the fuel properties of the larval grease-based biodiesel found to meet European standards (Zheng *et al*., 2012).

2.9 Factors affecting broiler chicken performance

Performance of commercial broiler chicken is determined by flock live-ability, average daily gain and efficiency of feed conversion. Any factor that affects these parameters will therefore influence overall performance.

2.9.2 Dietary factors

Inclusion of 1.25% lysine (highest recommended levels according to NRC, 1994) in starter and grower-finisher broiler diet affect performance by increasing both breast meat weight and yield (Kidd *et al.,* 1998) whereas addition of moderate amounts of insoluble fiber in broiler diet improves growth performance (Jiménez-Moreno *et al.,*2016). Broiler chicken performance is also affected by fatty acid composition of the dietary fat source (Józefiak *et al.,* 2014). Dietary energy level, energy to protein ratio, amino acid balance, type of protein and ambient temperature also affect broiler performance.

2.10 Quality Indices of broiler meat

A high quality broiler chicken is defined as one that contains less abdominal fat and more of breast and leg muscles. Consumers choose against abdominal fat because of its association with the risk of cardiovascular diseases (Micha *et al.*, 2010). Other quality indices include but not limited to appearance and tenderness together with the water holding capacity of the meat.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This study evaluated the performance and carcass quality of broiler chicken fed on diets containing Black soldier fly larvae (BSFL) meal.

The research protocol of this study was approved by both the University of Nairobi and the Kenya Agricultural and Livestock Research Organization (KALRO) animal care and use committees. The study was conducted for a period of two months (October and November 2016) at the Poultry Research Unit, Non-Ruminant Institute of the Kenya Agricultural and Livestock Research Organization in Naivasha, Kenya. Naivasha lies 0°43'S, 36°26'E along the Nairobi-Nakuru highway. The study area receives an annual average rainfall of 677mm and temperature of 17.1°C.

3.2 Insect meal

(Credit to Wachira Ngatia)

Plate 3. 1: Black Soldier Fly Larvae

Sun dried Black soldier fly larvae (BSFL) were procured from a company (Sanergy Ltd) located in Nairobi, Kenya. The larvae (Plate 3.1) were ground using a hammer mill having a detached perforated sieve at a commercial feed mill then mixed with other ingredients to obtain the experimental diets.

3.3 Experimental diets

Test diets were formulated according to the Kenya Bureau of Standards specifications for broiler starter and finisher mash feed. The diets as shown in Table 3.1 were formulated to contain a minimum 3000Kcal/kg ME, 220g CP/kg and 3000Kcal ME, 180g CP/kg in the starter and finisher diets respectively. Four dietary treatments containing Black Soldier Fly larvae (BSFL) meal at various inclusion levels were offered to 72 birds per treatment in 12 replicates of 6 birds each. The diets were as follows; C (0% BSFL meal) Control, L1 (5% BSFL meal), L2 (10% BSFL meal) and L3 (15% BSFL meal). These diets were formulated to replace soybean meal and or fishmeal (*Rastrineobola argentea*) while being iso-caloric and iso-nitrogenous. The BSFL meal replaced 13.3, 26.3 and 45.2% of soybean meal and 14.0, 30.0 and 35.0% of fishmeal in starter diets L1, L2 and L3 respectively while in the finisher diets L1, L2 and L3, the larvae replaced 19.0, 46.0 and 64.0% of soybean meal and 0, 25.0 and 43.8% of fish meal respectively.

Table 3. 1 : Ingredients (g/kg as fed) of experimental diets

	Broiler starter mash				Broiler finisher mash			
Ingredients	C	L1	L2	L3	C	L1	L2	L3
Maize grain	532.8	535.0	540.0	558.2	550.0	540.0	550.0	570.0
Wheat pollard	100.0	100.0	97.6	90.9	201.6	195.5	192.2	166.5
Corn oil	24.6	18.3	11.4	0.0	29.2	22.1	15.2	5.4
Soybean meal	225.4	195.6	166.1	123.6	111.1	90.0	60.0	40.0
Fish meal (Omena)	100.0	85.0	70.0	65.0	80.0	80.0	60.0	45.0
BSFL meal	0.0	50.0	100.0	150.0	0.0	50.0	100.0	150.0
L-Lysine	0.5	0.2	0.0	0.0	6.4	4.6	4.7	4.2
DL-Methionine	1.1	1.3	1.5	1.6	1.8	1.8	2.0	2.1
Dicalcium phosphate	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Limestone	9.0	8.0	7.0	4.2	13.4	9.6	9.4	10.3
Salt	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Broiler premix[1]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Mycotoxin binder	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ME[2] (kcal/kg)	2991.0	3011.0	3017.0	3060.0	3077.0	3056.0	3059.0	3141.0
NFE[2] (Nitrogen Free Extracts)	43.9	44.5	42.9	42.2	45.4	44.9	46.4	42.8

[1]*Vitamin and mineral premix provided the following per kg of diet: vitamin A, 11500IU;cholecalciferol,2100IU;vitaminE(fromdl-tocopherylacetate),22IU; vitamin B12, 0.60mg; riboflavin, 4.4mg; nicotinamide, 40mg; calcium pantothenate, 35mg; menadione (from menadione dimethyl-pyrimidinol), 1.50mg; folic acid, 0.80mg; thiamine, 3mg; pyridoxine, 10mg; biotin, 1mg; choline chloride, 560mg; ethoxyquin, 125mg; Mn (from MnSO4·H2O), 65mg; Zn (from ZnO), 55mg; Fe (from FeSO4·7H2O), 50mg; Cu (fromCuSO4·5H2O), 8mg; I (fromCa(IO3)2·H2O),1.8mg;Se,0.30mg;Co(fromCo2O3),0.20mg;Mo,0.16mg*.

[2] *Calculated chemical composition*

3.4 Experimental birds

Two hundred and eighty eight (n=288) mixed sex day old (Cobb 500) broiler chicks were sourced from a reputable hatchery in the country and reared for 49 days (7days adaptation phase and a 42days feeding phase). During the first 3 days of the acclimatization period, the chicks were reared together in a round deep litter floor brooder covered with 3 inch wood shavings as bedding and surrounded with a 3 feet high card board as the brooder wall. Three 250 Watts Infra-red bulbs were suspended 45cm over the brooder to offer source of heat. The chicks were feather sexed and moved to 48 brooder cages (each accommodating 6 chicks) where they were allowed to complete the 7-day acclimatization period. The chicks were provided 24 hours lighting for the first three days.

The chicks were fed a standard diet containing all the four experimental diets in equal quantities during the first 3 days of the adaptation period, before randomly being assigned to one of the four diet treatments to complete the remaining 4 days of the acclimatization period. After the 7 day adaptation period, the chicks were weighed and allowed to continue with the assigned diets for a 42 day feeding period. Fresh Clean water and feed were provided *ad libitum* daily.

The birds were housed in 48, concrete floor cages measuring 750mm in length by 900mm in width by 750mm in height spread out in a concrete wall poultry house having artificial ventilations (fans). Each cage sufficiently accommodated 6 birds and was fitted with a 250Watts, BR125 double reflector system infrared bulb to provide heating during the brooding period, a plastic feeder (shown by arrows) on the side (Plate 3.2) and one round 4L drinker inside each cage were provided. The L×W×H measurements of the feeder were 73cm by 26cm by 48cm. Eight holes on the side of the feeder facilitated the birds to access feed by only inserting their heads.

Plate 3. 2: Experimental cages fitted with infra-red bulbs

3.5 Experimental design

The study adopted a completely randomized design with 72 birds per treatment replicated twelve times (six birds/replica).

3.6 Data collection

The experiment took 49 days, a 7 day adaptation period, followed by a continuous 42d feeding period and a one day (50th day) for slaughtering. All measurements on body weight, feed intake, and carcass weight were recorded using a digital (SHIMADZU-TXB6201L) scale.

3.6.1 Growth and feed intake

The birds in a cage were put in a tared plastic bucket and their weight taken on a weekly (Every Friday at 0800Hrs) basis. Feed intake was monitored weekly by placing a known amount of feed (2Kg in week one then subsequently increased by 2Kg every week) for each cage in a 20 L plastic bucket (top diameter of 36 cm, bottom diameter of 26cm and a height of 29cm) at the start of each week. The weight of feed consumed per cage was calculated by difference (weight of feed in the bucket at end of the week subtracted from the weight of the feed in the bucket at the start of the week). The average daily gain (ADG) and average daily feed intake (ADFI) were calculated. Any mortality observed was recorded.

3.6.2 Carcass characteristic

Two birds from each replicate cage were sacrificed on the 50^{th} day (by dislocating the cervical joint) after an overnight fast to determine the carcass dressing percentage, abdominal fat and the breast and thigh muscle weights. Slaughtering was done at the poultry research unit slaughter facility located at the study site, which is equipped with an electric stunner, rotating bleeding stainless steel table and electric-heated water bath for scalding. Dressed carcasses from each cage were weighed and recorded. Carcass parts (thigh, breast, wings, back) and internal structures (abdominal fat, heart, liver and spleen) were harvested to determine their weight.

3.6.3 Organoleptic test

Twenty four dressed carcasses (6 per treatment) were chilled at 4°C and transported to the sensory test laboratory of the Department of Food Science and Technology, University of Nairobi where organoleptic tests were done on the pectoral muscle as described by Atapattu &

Silva (2016). Ten semi-trained volunteers were recruited to take part in the organoleptic analysis. The volunteers were 3 female and 7 male aged between 20 and 40 years. They were provided with water to rinse their mouths between samples as described by Atapattu & Silva (2016). Taste and aroma were the two sensory parameters evaluated using a 9 point hedonic scale where 1 was extreme dislike, 5 was neither like nor dislike while 9 was extreme like (Appendix 34).

3.7 Chemical Analysis

Chemical composition of the experimental diets, soybean meal, fishmeal and BSFL meal were determined using the procedures described by the Association of Official Analytical Chemists (AOAC, 1990). Dry matter was estimated by oven drying the samples at 105°C for 12 hours (method no 967.03), Ash content was determined by burning the samples at 600°C for 3 hours in a muffle furnace (method no 942.05), Ether extract was calculated by exposing the sample in diethyl ether using a Solvent extractor SER 148/6 and weighing the dried extract (method no 920.29), Crude protein (CP) was estimated using the Kjeldahl method where an automatic Kjeldahl digestion unit-DKL/20 and UDK 159 automatic Kjeldahl analyzer were used to measure the Nitrogen (N) content of the sample. The CP was estimated by multiplying the N content by the factor 6.25.The sample was digested in sulfuric acid and potassium hydroxide to estimate the crude fiber content.

Amino acid analysis of BSFL meal was determined according to Method 994.12 of the Association of Official Analytical Chemists (AOAC, 2000). Samples were hydrolyzed in 6M HCL at 112°C for 22 hours. Performic acid oxidation occurred prior to acid hydrolysis. The amino acid hydrolysate was determined by HPLC at the Evonik Nutrition & care GmbH Amino lab.

Nitrogen free extracts (NFE) and Metabolizable energy (ME) of the experimental diets were estimated. NFE was expressed as a percentage using the formulae; 100 - (Moisture content + CP + EE + CF + Ash). Predictive equations using the proximate analysis data of the treatments was used to estimate the ME of the diets.

$$ME = -0.45 + (1.01 \times DE)$$

Where;

$$DE \text{ (Digestible Energy)} = TDN \times 4.409/100$$

$$TDN \text{ (Total Digestible Nutrients)} = 54.6 + 3.66 \times CP - 0.26 \times CF + 6.85 \times EE$$

3.8 Economic analysis

The Cost benefit analysis (CBA) and Return on investment (RoI) were the two indices used in evaluating the economic implication of BSFL meal inclusion in broiler chicken diets.

3.8.1 Cost Benefit Analysis (CBA)

Cost benefit analysis is a methodical approach of evaluating all the costs and benefits (expressed in monetary terms) of a project to determine its economic viability against alternative projects. Total cost of production included feed, labour, medication, water, electricity, housing, drinkers, and feeders but only the cost of the feed was considered during the calculation of the project costs as the rest were assumed to be constant for all the treatments. Feed costs were calculated from the ingredient prices based on quantities of each incorporated in the dietary feed treatments.

Costs of ingredients at the time of the study are shown in appendix 32. Revenue collected from sale of the broilers at the end of the feeding phase was assumed to represent all the benefits accrued from the project. The ratio between the project revenue and the project cost represent the Cost Benefit Ratio (CBR).Cost benefit ratio above one means that the benefits of the project exceeded the costs and vice versa.

$$\text{Cost Benefit Ratio (CBR)} = \frac{\text{Project revenue}}{\text{Project cost}}$$

3.8.2 Return on Investment (RoI)

Return on investment is a parameter used to measure the gain/loss generated from an investment relative to the money investment. It is calculated by dividing the profit by the cost and the result expressed as a percentage. Profit is the difference between the project revenue and the project cost. The higher the RoI value the better the return on investment.

$$\text{Return on Investment (RoI)} = \frac{\text{Project revenue} - \text{Project cost}}{\text{Project cost}} \text{ x } 100$$

3.9 Statistical Analysis

Data on weight gain, feed intake, carcass characteristics and organoleptic test was analyzed using a one way analysis of variance (ANOVA) with the four BSFL meal inclusion levels (0%, 5%, 10% and 15%) being factors. The statistical package R version 3.3.2 was used. Each pen represented an experimental unit while each bird as an experimental unit for carcass characteristics. The significance between the treatment means was tested at statistical significance level of 5% and where significant, separated using Tukey's multiple comparison procedure.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Chemical composition of Black Soldier Fly Larvae (BSFL) meal and selected protein ingredients

Chemical composition of Black Soldier Fly Larvae (BSFL) meal and the main protein ingredients used in the study are shown in Table 4.1. The Crude protein (CP) of the BSFL meal value was higher compared to 36.9% (De Marco *et al.*, 2015), 42.1% (Makkar *et al.*, 2014) and 41.7% (AMINOLab, 2016).

Table 4. 1: Chemical composition (% DM basis) of BSFL meal, Fish meal and Soybean meal

	BSFL meal	Fish meal	Soybean meal
Dry matter (DM)	97.0	93.0	92.2
Crude protein (CP)	43.9	42.7	49.4
Ether extract (EE)	29.4	6.4	2.1
Crude fiber (CF)	21.3	1.2	8.6
Ash	13.2	50.2	6.8

This disparity in CP can be attributed to the fact that the larvae used in the study were reared on solid waste substrate which might be different from those cited. Tschirner and Simon (2015) reared Black Soldier Fly larvae on a middling mixture, dried distillers grain with soluble (DDGS) and dried sugar beet pulp. The resultant larvae attained a CP level of 37.2, 44.6 and 52.3% respectively. They concluded that substrate type greatly impacts the total yield of BSFL meal and their composition. In another study, Black Soldier Fly pre-pupae CP levels varied between 39.9 and 43.1% (DM basis) while ether extract and ash content differed substantially when larvae were reared on different substrates (Spranghers *et al.*, 2016).

The ether extract content of the larvae was higher than 26.0% reported by Makkar *et al.*, (2014) and lower than 34.3% reported by De Marco *et al.*, (2015). Differences in the EE levels may also result from variation in substrate used during production (Makkar *et al.*, 2014) as previously discussed above. In this study, the substrate used for rearing was not known. Defatted BSFL meal is produced by applying tincture press to sliced (slicing facilitates leakage of intracellular fat) larvae (Kroeckel *et al.*, 2012). Ash contains the inorganic or mineral content of a feed. Black Soldier Fly larvae are high in ash with values of between 11-28% (Makkar *et al.*, 2014) and 12.6% (Bosch *et al.*, 2014) having been reported. The value obtained in this study of 13.2% is within the reported ranges. Chitin in the exoskeleton of the larvae is the source of the ash component in the BSFL meal.

It is assumed that fiber in insects is represented by chitin present in their exoskeleton (Finke, 2007). The CF of the larvae was 21.3%, higher than 7% reported by Newton *et al.*, (2005). Fishmeal had a CP value of 42.7% which is within the range 40-50% CP reported by (NRC, 1994; Willis 2003; Van Eys *et al*., 2004) but lower than 60.3% (AMINODat). The lower CP and high ash content of 50.2% compared to 19.1% (AMINODat) maybe attributed to poor quality discussed in the literature review (Page 7). The CP of soybean meal used in the current study was 49.4%, EE of 2.1%, CF of 8.6% and ash 6.8%. Ravindran *et al.*, (2014) when comparing nutrient composition of soybean meal sourced from different countries, noted that major nutritional differences exist due to source of origin.

4.2 Amino acid profile of Black Soldier Fly larvae

The amino acid composition of the Black Soldier Fly larvae (BSFL) meal used in this study is shown in Table 4.2. The two most limiting amino acids in practical poultry diets are methionine and lysine (NRC, 1994). The methionine and lysine level in BSFL meal were 0.80% and 2.81% respectively. Methionine level was similar to 0.76% recorded by Spranghers *et al.*, (2016) but lower than 0.91% DM (De Marco *et al.,* 2015) whereas lysine levels are higher than (2.34% DM and 2.23% DM) recorded by Spranghers *et al.,* (2016) and De Marco *et al.,* 2015 respectively. When comparing these amino acids with those of soybean meal and fish meal reported by Liebert (2017), it is evident that methionine level in BSFPM is higher than that of SBM (0.62% DM) but lower than in fishmeal (1.50% DM) while lysine content is comparable to that of soybean meal (2.81% DM) but lower than in fishmeal (4.09% DM).

Table 4. 2: Amino acid profile of Black Soldier Fly larvae (BSFL) meal

Amino acid	Content (% DM basis)
Methionine	0.80
Cystine	0.35
Lysine	2.81
Threonine	1.63
Arginine	2.11
Isoleucine	1.77
Leucine	2.78
Valine	2.50
Histidine	1.35
Phenylalanine	1.64
Glycine	2.46
Serine	1.76
Proline	2.36
Alanine	2.56
Aspartic acid	3.87
Glutamic acid	4.61

4.3 Chemical composition of experimental diets

Chemical composition of the experimental diets used in the study is shown in Table 4.3. The crude protein (CP) level of the formulated diets attained the minimum requirement of 22% and 18% CP in broiler starter and finisher feed respectively. Although the diets were formulated to be iso-caloric and iso-nitrogenous, analyses show that the starter and finisher feed of all the diets had a CP of between 22% and 23%. The difference in CP content between formulated and actual diet could be due to variability in CP content of raw materials some of which were not analyzed prior to inclusion.

The diet with the highest level of Black Soldier Fly Larvae inclusion (diet L3) had the highest ether extract concentration (8.5% and 11.0%), least ash content (8.6% and 6.6%) and highest crude fiber (7.2% and 6.8%) in the starter and finisher diets respectively. The high ash content may have resulted from the suspected adulteration of fish meal used in the study with ash and also from the exoskeleton of the BSFL.

Table 4. 3: Chemical analysis (% DM basis) and energy content of experimental broiler diets

	Broiler Starter Mash				Broiler Finisher Mash			
	C	L1	L2	L3	C	L1	L2	L3
Dry matter	89.6	89.7	89.1	89.3	89.2	89.1	89.3	89.6
Crude protein (CP)	22.1	21.5	23.1	22.8	21.6	22.8	21.5	22.4
Ether extract (EE)	6.8	7.1	7.2	8.5	8.6	8.1	8.3	11.0
Crude fiber (CF)	6.9	5.9	6.8	7.2	5.3	6.3	5.9	6.8
Ash	9.9	10.7	9.1	8.6	8.3	7.0	7.2	6.6

4.4 Broiler chicken performance

The effect of including BSFL meal in broiler diets on broiler chicken performance during the starter and finisher feeding phases are shown in Table 4.4. There was no treatment effect on average daily feed intake (ADFI) (*P*=0.197) and feed conversion ratio (FCR) (*P*=0.455) during the entire feeding period. However, the final body weight of the broiler chicken were significantly different between diet L1 and L2 (*P*=0.042).

Daily body weight gain (BWG) showed a similar trend (*P* =0.044) to that observed in final body weights. The broilers had similar initial body weights, final body weights, BWG, ADFI and FCR for all the dietary treatments during the starter phase. This trend was maintained during the finisher phase except that a difference (*P* =0.042) between the final body weights was observed. Birds fed on diet L1 had heavier live weight (3182 g) than diet L2 (3006 g). Although in this study the final body weight (*P* =0.042) and the average daily BWG (*P* =0.044) during the entire feeding phase showed significant difference between treatment means, the difference was only between diet L1 and L2.

Table 4. 4: Effect of partial replacement of soybean meal and fish meal with BSFL meal in broiler diets on performance

	Experimental diets					
	C	L1	L2	L3	SEM	*P* value
Starter phase (d7-d28)						
Initial weight (g)	171.3	169.0	169.2	165.5	2.74	0.227
Final weight (g)	1425.4	1425.6	1397.3	1362.2	30.11	0.133
BWG[1] g/bird per day	59.7	59.8	58.5	57.0	1.39	0.159
ADFI[1] (g/bird per day)	90.9	90.0	89.2	87.6	1.66	0.243
FCR[1]	1.5	1.5	1.5	1.5	0.02	0.498
Finisher phase (d28-d49)						
Initial weight (g)	1425.4	1425.6	1397.3	1362.2	30.11	0.133
Final weight (g)	3071.0[ab]	3182.0[a]	3006.0[b]	3033.0[ab]	62.71	0.042
BWG[1] g/bird per day	78.4	83.6	76.6	79.6	3.21	0.181
ADFI[1] (g/bird per day)	157.3	162.4	156.6	150.7	5.57	0.233
FCR[1]	2.0	1.9	2.0	1.9	0.10	0.369
Entire Feeding phase						
Initial weight (g)	171.3	169.0	169.2	165.5	2.74	0.227
Final weight (g)	3071.0[ab]	3182.0[a]	3006.0[b]	3033.0[ab]	62.71	0.042
BWG[1] g/bird per day	69.0[ab]	71.7[a]	67.6[b]	68.3[ab]	1.49	0.044
ADFI[1] (g/bird per day)	124.1	126.2	122.9	119.1	3.29	0.197
FCR[1]	1.8	1.8	1.8	1.7	0.05	0.455

Means in a row with no/similar superscript letter are not significantly different (p>0.05)

[1]BWG – Body Weight Gain, ADFI – Daily Feed Intake, FCR – Feed Conversion Ratio

It can therefore be deduced that dietary inclusion of BSFL meal had no effect on body weight at slaughter, average daily BWG (Figure 4.1), ADFI and FCR but rather the difference observed be attributed to the fact that fish meal level in L1 was maintained while soybean meal level lowered compared to L2 where both fish meal and soybean meal levels were lowered as BSFL meal was added. Diet L1 had therefore more animal (fish meal and BSFL meal) based protein than L2. Fish meal has unidentified growth factors (Ravindran, 2013) which probably contributed to the 5.9% higher weight at slaughter and 5.6% higher body weight gain of birds reared on L1 than L2. The fact that birds fed on diet C (control diet) recorded similar final body weights to all the other diets confirms this.

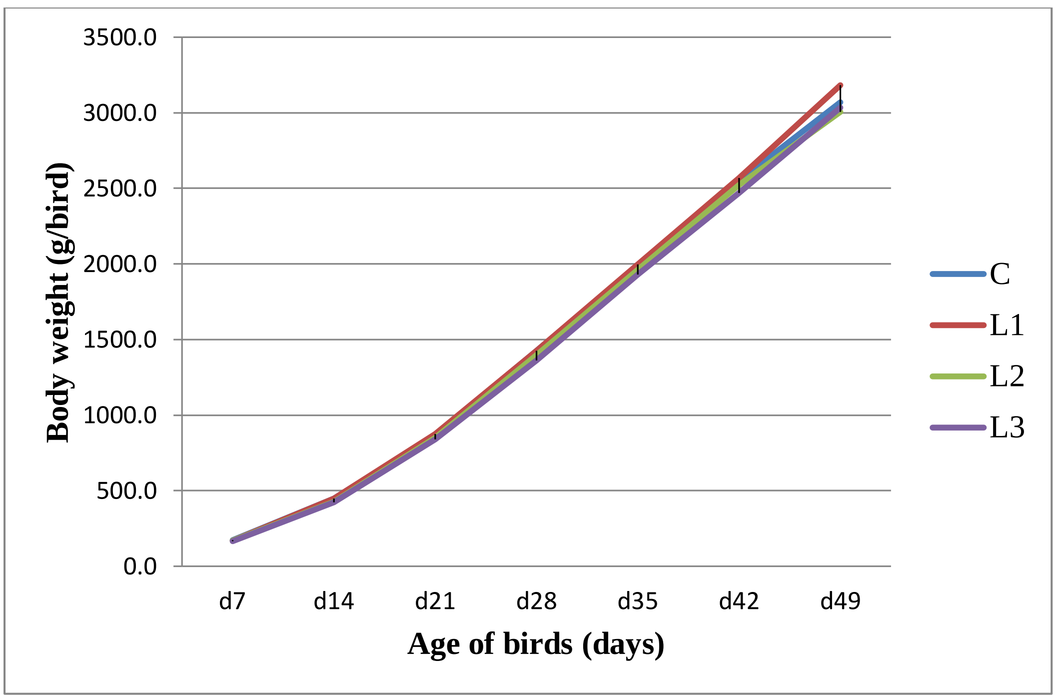

Figure 4. 1: Effect of partial dietary replacement of soybean meal and fish meal with BSFL meal in broiler diets on body weight

Cullere *et al.,* (2016) reported similar results when intensively reared growing quails were fed on defatted BSFL meal. Elwert *et al*., (2010) observed similar results when full fat BSFL meal were included in broiler starter diet. Leiber *et al.,* (2015) conducted a study to determine the effect of including BSFL meal as an insect based protein source in slow growing organic broilers diets on the growth performance and physical meat quality of the birds. Their findings indicated that similar feed efficiency and product quality can be attained when part of soybean products are replaced by insect meal in broiler diets. Dietary inclusion of BSFL meal in broiler diets had therefore no adverse effect on performance of the broiler chicken.

4.5 Broiler chicken carcass characteristics

The effect of dietary inclusion of the BSF larvae meal in broiler diet on carcass characteristics is shown in Table 4.5. There were no significant effects of BSFL meal inclusion on breast meat weight (p=0.159), abdominal fat content (p=0.094) and internal organs; liver (p=0.326), heart (p=0.282), gizzard (p=0.978), spleen, p=0.957) weights between treatments. The percentage of the breast meat produced by the broilers in all the treatments ranged between 34.0 to 38.5% of the dressed weight. Cullere *et al.,* (2016) fed broiler quails on 0, 10 and 15% inclusion levels of BSFL meal and reported a 30.7, 30.8 and 30.7% breast meat yield respectively. Their results are within the range observed in the current study. The average dressed carcass percentages of the breast meat and abdominal fat across all treatments were higher than those reported by Nawaz *et al.,* (2016); 20.25% and 2.63% breast and abdominal fat respectively.

Table 4. 5: Effect of partial replacement of soybean meal and fish meal with BSFL meal in broiler diets on carcass traits

	Experimental diets									
	C		**L1**		**L2**		**L3**			
Dressed weight g/bird	2409.0		2423.9		2412.4		2300.9			
	Wt (g)	**[%][1]**	Wt (g)	**[%][1]**	Wt (g)	**[%][1]**	Wt (g)	**[%][1]**	SEM	*P* value
Breast	818.1	34.0	913.6	37.7	928.4	38.5	848.4	36.9	54.06	0.159
Abdominal fat	70.0	2.9	83.7	3.5	107.0	4.4	89.6	3.9	14.03	0.094
Liver	47.4	2.0	50.6	2.1	52.3	2.2	51.4	2.2	2.72	0.326
Gizzard	41.7	1.7	43.4	1.8	42.7	1.8	43.0	1.9	4.02	0.978
Heart	12.9	0.5	14.0	0.6	15.7	0.7	13.9	0.6	1.44	0.282
Spleen	3.6	0.2	3.4	0.1	3.7	0.2	3.4	0.1	0.68	0.957

[%][1] % Dressed weight

Nawaz *et al.*, (2016) fed the birds on a corn, soybean meal and fish meal based diet for 35 days unlike in the current study where the birds were fed for 42 days. The 7 day difference in slaughter age might explain the higher dressing percentage. Increasing the slaughter age of chicken significantly raises the dressing percentage regardless of genotype De Silva *et al.*, (2016).

4.6 Broiler chicken breast meat flavor

Sensory tests on breast meat from broilers fed on the experimental diets are shown in Table 4.6. The BSFL meal inclusion had no effect on the aroma, taste and overall acceptability of cooked breast meat. All the treatments recorded a point 5 and above on the hedonic scale. Sealey *et al.*, (2011) recorded similar results when 30 untrained panelists couldn't tell any significant difference between fish fed diets enriched with up to 50% Black Soldier Fly larvae inclusion.

There are several factors that influence consumer preferences on broiler meat consumption, top being meat flavor. Chicken meat flavor results from volatile compounds generated from lipid degradation, maillard reaction or the interaction between these two after heating (Shi and Ho, 1994). Flavor is therefore a reserve of cooked meat as opposed to raw.

Taste and smell (aroma) are the two sensory attributes that are collectively termed as flavor. Chicken diet, fatty acid composition, lipid class and glutamic acid content of the meat, are among other factors that influence cooked chicken meat flavor (Jayasena *et al.*, 2013). In the current study, the cooked breast meat (pectoral muscle) of broiler chicken fed on all the experimental diets recorded similarities (point 5 and above) on aroma, taste and overall acceptability. The sensory test results suggest that inclusion of BSFL meal in broiler diets will not affect consumer preference.

Table 4. 6: Sensory evaluation of cooked pectoral muscle of broilers fed on diets containing BSFL meal

	Experimental diets					
	C	L1	L2	L3	SEM	*P* value
Aroma[1]	6.167	5.600	6.067	5.200	0.387	0.051
Taste[1]	5.900	5.367	5.900	5.333	0.441	0.379
Overall acceptability[1]	6.067	5.700	6.233	5.600	0.387	0.314

[1] Aroma, taste and overall acceptability were evaluated using a 9-point hedonic scale, where 1 = extremely dislike and 9 = extremely like

4.7 Economic analysis of BSFL meal inclusion

Economic analysis of partially replacing soybean meal and fish meal with BSFL meal in broiler diets is shown in Table 4.7. In conducting this analysis, it was assumed that the cost of ingredients and the sale of live birds at the end of the feeding trial were the only source of costs and profits respectively. The price of starter and finisher diets (Ksh/Kg) gradually reduced as more soybean meal and fish meal were replaced with BSFL meal with starter and finisher diet L3 being 11.4% and 10.3% cheaper respectively than the conventional diet. The starter phase, finisher phase and cumulative feed intake were similar for all the treatments, with an average of 1872.2g, 3292.3g and 5170.5g in the starter, finisher and cumulative phases respectively. These feed intake values are higher than those recommended by NRC (1994) of 1553g, 3102g and 4654g for the starter, finisher and cumulative phases respectively. The higher levels of feed intake observed in the study may be attributed to the fact that the experimental diets were formulated to attain an energy level of 3000Kcal ME/kg which is lower than the NRC (1994) broiler diets which provided 3200 Kcal ME/Kg and that the birds were reared for 7 weeks unlike the recommended 6 weeks. Poultry tend to feed to meet their energy requirements and as such, feed consumption is lowered when feeding on high energy diets.

Table 4.7: Economic analysis of replacing soybean meal and fish meal with BSFL meal in broiler diets

	Experimental diets					
	C	L1	L2	L3	SEM	*P* value
Cost of feed (Ksh/kg)						
Starter feed	61.5	59.6	57.5	54.5		
Finisher feed	57.4	56.1	53.8	51.5		
Feed intake (g/bird)						
Starter phase	1909.2	1890.6	1874.0	1839.3	34.77	0.243
Finisher phase	3304.0	3411.0	3289.0	3164.0	117.0	0.233
Cumulative feed intake	5213.2	5301.6	5163.0	5003.3	138.0	0.197
Cost of feed (Ksh/bird)						
Starter phase	117.4^{a}	112.7^{ab}	107.8^{b}	100.2^{c}	2.039	<0.001
Finisher phase	189.7^{a}	191.4^{a}	177.0^{ab}	163.0^{b}	6.371	<0.001
Total Feed Cost (C)	307.1^{a}	304.1^{ab}	284.8^{b}	263.2^{c}	7.622	<0.001
Live weight at slaughter (g)	3071.0^{ab}	3182.0^{a}	3006.0^{b}	3033.0^{ab}	62.71	0.042
Sale of birds[1] (S)	767.8^{ab}	795.5^{a}	751.5^{b}	758.3^{ab}	15.68	0.042
Gross profit margin[2] (P)	460.7	491.4	466.7	495.1	15.76	0.263
Cost Benefit Ratio[3] (CBR)	2.5^{b}	2.6^{b}	2.6^{b}	2.9^{a}	0.075	<0.001
Return on Investment[4] (RoI)	150.0^{b}	161.6^{b}	163.9^{b}	188.1^{a}	7.461	<0.001

*[1]250 Ksh/Kg Live weight, [2]P = S - C, [3]CBR = S/C, [4]RoI = {S-C}/C*100*
Currency exchange rate at the time of study (1USD for 100Ksh)

Cost of consumed feed in Ksh/bird during the starter phase when birds were fed diet L3 was 14.7% lower than the conventional feed. Cost of consumed feed in Ksh/bird for birds reared on diet L1 and L2 during the same feeding phase was comparable while the conventional feed was only comparable to L1. Although the starter feed intake was similar in all the experimental diets, feeding broilers on diet L3 was the cheapest because of the lowest cost of starter feed (54.5 Ksh/Kg). The starter feed price of the conventional diet was highest (61.5 Ksh/Kg), explaining the observed highest cost (117.40 Ksh/bird) of rearing birds during this feeding phase. During the finisher phase, the cost of consumed feed across the diets was different ($p<0.001$). Feeding the birds on a finisher diet L3 resulted in the lowest feed costs (163.0Ksh/bird), a 14.1% lower cost than the conventional diet. While diet L1 gave the highest feed cost (191.40Ksh/bird) numerically, it was comparable to both the conventional diet and diet L2. Cumulatively, in terms of all feed consumed during the starter and finisher phases, the conventional diet (307.1Ksh/bird) and diet L1 (304.1Ksh/bird) were the most expensive while diet L3 was the cheapest (263.20 Ksh/bird). Diet L2 was comparable to L1. As intended, the cost of ingested feed gradually decreased starting from the control to diet L3 with increased replacement of soybean meal and fish meal with BSFL meal in the diets.

Broilers that were fed on diet L1were the heaviest while those on diet L2 the lightest. These birds attained significantly different live weights at slaughter of 3182g and 3006g respectively. Those on diet L3 and control attained similar live weight at slaughter and comparable to those fed on either diet L1 or L2. Birds were sold on a live weight basis at 250Ksh/Kg meaning that heavier birds fetched higher prices. Birds fed on diet L1 fetched the highest selling price (795.40Ksh) while diet L2 the least (751.60Ksh). Gross profit margins were assumed to be the difference between the total cost of feeds and sale of birds on a live weight basis. According to these assumptions birds fed on all the test diets recorded statistically similar gross profit margins. The Cost Benefit Ratio (CBR) however revealed that birds fed on diet L3 had a 16.0% higher CBR (2.9) than those on the conventional diet (2.5) while birds reared on diet L1 and L2 recorded similar CBR (2.6) and that both were comparable to the conventional diet. Calculated Returns on Investment (RoI) recorded similar trends to that of the CBR in all the test diets only that RoI of L3 was 25.0% better than the conventional diet.

According to the economic analysis, diet L3 recorded the highest Cost Benefit Ratio (CBR) and best Returns on Investment (RoI) while diet L1, L2 and the conventional diet recorded the least CBR and RoI. Based on the economic analysis, it can be summarized that 15% dietary inclusion of BSFL meal in broiler chicken diets replacing 45.2 and 64.0% of soybean meal and 35.0 and 43.8% of fish meal in broiler starter and finisher diets respectively is recommended because of its high CBR and Return on Investment.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study was conducted to determine the effect of partially replacing the more expensive conventional feed protein ingredients; soybean meal and fish meal with Black Soldier Fly larvae (BSFL) meal in broiler diets on performance, carcass characteristics, sensory attributes of cooked breast muscle and economic implication of its use. It is therefore concluded that:

1. Inclusion of Black Soldier Fly Larvae (BSFL) meal up to 15% in broiler diets replaced 45.2 and 64.0% of soybean meal and 35.0 and 43.8% of fish meal (conventional feed protein ingredients) in broiler starter and finisher diet respectively without affecting average daily intake, body weight gain and feed conversion ratio of the birds
2. Dietary replacement of 45.2 and 64.0% of soybean meal and 35.0 and 43.8% of fish meal with BSFL in broiler starter and finisher diets respectively does not affect the aroma, taste and overall acceptability of cooked breast meat.
3. Dietary inclusion of 15% BSFL meal to partially replace soybean meal and fish meal in broiler starter and finisher diets reduced the feed price by 11.4% and 10.3% respectively and increased the RoI by 25.0% and CBR by 16.0%.

5.2 Recommendations

Although these results are promising, Black soldier fly prepupae meal is not common in the market and therefore further work to promote its rearing (use of different available substrates and various processing methods) and commercialization is needed in order to achieve the full potential of its use as a protein feed ingredient in broiler chicken feeds.

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APPENDICES

Appendix 1: Analysis of Variance table of initial body weight (g) d7

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	170.6	56.86	1.515	0.227
Residuals	36	1351.6	37.55		
Total	39	1522.2			

SEM = 2.74

Appendix 2: Analysis of Variance table of d49 final body weight (g)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	178175	59392	3.02	0.0422
Residuals	36	707862	19663		
Total	39	886037			

SEM = 62.71

Appendix 3: Analysis of Variance table of Body Weight Gain (g/day) d7-d49

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	99.7	33.23	2.979	0.0442
Residuals	36	401.7	11.16		
Total	39	501.4			

SEM = 1.494

Appendix 4: Analysis of Variance table of daily feed intake (g/day) d7-d49

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	265.8	88.58	1.641	0.197
Residuals	36	1943.8	53.99		
Total	39	2209.6			

SEM = 3.286

Appendix 5: Analysis of Variance table of FCR (Feed Conversion Ratio) d7-d49

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	0.0377	0.01256	0.892	0.455
Residuals	36	0.5070	0.01409		
Total	39	0.5447			

SEM = 0.05307

Appendix 6: Analysis of Variance table of starter phase final body weight (g) d28

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	27092	9031	1.992	0.133
Residuals	36	163177	4533		
Total	39	190269			

SEM = 30.11

Appendix 7: Analysis of Variance table of Starter phase Body Weight Gain (g/day) d7-d28

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	53.1	17.709	1.832	0.159
Residuals	36	348.0	9.667		
Total	39	401.1			

SEM = 1.39

Appendix 8: Analysis of Variance table of starter phase daily feed intake (g/day) d7-d28

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	59.9	19.97	1.457	0.243
Residuals	36	493.5	13.71		
Total	39	553.4			

SEM = 1.656

Appendix 9: Analysis of Variance table of starter phase FCR (d7-d28)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	0.00596	0.001988	0.807	0.498
Residuals	36	0.08863	0.002462		
Total	39	0.09459			

SEM = 0.02219

Appendix 10: Analysis of Variance table of finisher phase BWG (d28-d49)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	264.9	88.3	1.716	0.181
Residuals	36	1852.1	51.45		
Total	39	2117			

SEM = 3.208

Appendix 11: Analysis of Variance table of finisher phase ADI (g/day) d28-d49

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	694	231.4	1.492	0.233
Residuals	36	5584	155.1		
Total	39	6278			

SEM = 5.57

Appendix 12: Analysis of Variance table of finisher phase FCR (d28-d49)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	0.1681	0.05605	1.083	0.369
Residuals	36	1.8627	0.05174		
Total	39	2.0308			

SEM = 0.1017

Appendix 13: Analysis of Variance table of breast muscle weight (g)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	57839	19280	1.885	0.159
Residuals	24	245498	10229		
Total	27	303337			

SEM = 54.06

Appendix 14: Analysis of Variance table of abdominal fat weight (g)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	4936	1645.2	2.389	0.0938
Residuals	24	16529	688.7		
Total	27	21465			

SEM = 14.03

Appendix 15: Analysis of Variance table of Liver weight (g)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	94.3	31.43	1.215	0.326
Residuals	24	620.6	25.86		
Total	27	714.9			

SEM = 2.718

Appendix 16: Analysis of Variance table of Gizzard weight (g)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	11.1	3.71	0.066	0.978
Residuals	24	1358.6	56.61		
Total	27	1369.7			

SEM = 4.022

Appendix 17: Analysis of Variance table of Heart weight (g)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	29.54	9.845	1.349	0.282
Residuals	24	175.14	7.298		
Total	27	204.68			

SEM = 1.444

Appendix 18: Analysis of Variance table of Spleen weight (g)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	0.5	0.1681	0.104	0.957
Residuals	24	38.84	1.6183		
Total	27	39.34			

SEM = 0.68

Appendix 19: Analysis of Variance table of Breast muscle Aroma

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	17.96	5.986	2.67	0.0508
Residuals	116	260.03	2.242		
Total	119	277.99			

SEM = 0.3866

Appendix 20: Analysis of Variance table of Breast muscle Taste

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	9.1	3.031	1.037	0.379
Residuals	116	339.0	2.923		
Total	119	348.1			

SEM = 0.4414

Appendix 21: Analysis of Variance table of Breast muscle Overall acceptability

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	8.07	2.689	1.196	0.314
Residuals	116	260.73	2.248		
Total	119	268.8			

SEM = 0.3871

Appendix 22: Analysis of Variance table of Starter phase feed intake

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	26415	8805	1.457	0.243
Residuals	36	217615	6045		
Total	39	244030			

SEM = 34.77

Appendix 23: Analysis of Variance table of Finisher phase feed intake

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	306086	102029	1.492	0.233
Residuals	36	2462424	68401		
Total	39	2768510			

SEM = 117

Appendix 24: Analysis of Variance table of Starter phase feed cost

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	1614.7	538.2	25.9	<0.001
Residuals	36	748.1	20.8		
Total	39	2362.8			

SEM = 2.039

Appendix 25: Analysis of Variance table of Finisher phase feed Cost

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	5212	1737.3	8.561	<0.001
Residuals	36	7305	202.9		
Total	39	12517			

SEM = 6.371

Appendix 26: Analysis of Variance table of Total feed Cost

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	12334	4111	14.15	<0.001
Residuals	36	10458	291		
Total	39	22792			

SEM = 7.622

Appendix 27: Analysis of Variance table of Sale of birds

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	11136	3712	3.02	0.0422
Residuals	36	44241	1229		
Total	39	55377			

SEM = 15.68

Appendix 28: Analysis of Variance table of Gross profit margins

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	8906	2969	2.399	0.084
Residuals	36	44555	1238		
Total	39	53461			

SEM = 15.73

Appendix 29: Analysis of Variance table of Cost Benefit Ratio (CBR)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	0.7571	0.25238	9.067	<0.001
Residuals	36	1.0021	0.02784		
Total	39	1.7592			

SEM = 0.07461

Appendix 30: Analysis of Variance table of Return on Investment (RoI)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	7571	2523.8	9.067	<0.001
Residuals	36	10021	278.4		
Total	39	17592			

SEM = 7.461

Appendix 31: Analysis of Variance table of Cumulative feed intake

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Inclusion levels	3	468790	156263	1.641	0.197
Residuals	36	3428895	95247		
Total	39	3897685			

SEM = 138

Appendix 32: Cost (Ksh/Kg) of Ingredients used in feed formulation of the experimental diets

Ingredient	Cost (Ksh/Kg)
Maize grain	32.0
Pollard	25.0
Corn oil	280.0
Soybean meal	90.0
Fish meal (*Rastrineobola argentea*)	120.0
BSFL meal	85.0
Lysine	600.0
Methionine	850.0
DCP	80.0
Limestone	10.0
Salt	20.0
Premix	400.0
Mycotoxin binder	320.0

Appendix 33: Broiler vaccination program

Age (days)	Vaccine Type	Route of administration
8	Infectious Bursal disease (Gumboro)	Drinking water
10	Newcastle + infectious bronchitis (NCD+IB)	Drinking water
15	Infectious Bursal disease (Gumboro)	Drinking water
24	Newcastle + infectious bronchitis (NCD+IB)	Drinking water

Appendix 34: Questionnaire administered to taste panelists during organoleptic test evaluation

ORGANOLEPTIC EVALUATION OF COOKED BROILER MEAT SAMPLES

Name: ……………………………………………………………………………….

Age: (Indicate either below 20yrs, >20yrs, >30yrs or above 40yrs) ……………….

Date: ………………….

Panelist # …………….

Forty eight (24) cooked broiler meat samples will be provided to you in 3 sets of 8 samples each.

You are expected to employ your sense of sight, touch, smell and taste to evaluate the samples. Use the Hedonic scale (1 to 9) provided to rate the samples.

HEDONIC SCALE

1. Dislike extremely

2 .Dislike very much

3 .Dislike moderately

4 .Dislike slightly

5. Neither like nor dislike

6 .Like slightly

7 .Like moderately

8 .Like very much

9 .Like extremely

Sample #	**Appearance**	**Color**	**Texture**	**Mouth-feel**	**Aroma**	**Taste**	**Overall acceptability**
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							