EFFECT OF BLACK SOLDIER FLY (*Hermetia illucens*) LARVAE MEAL ON THE LAYING PERFORMANCE OF IMPROVED KENYAN INDIGENOUS CHICKEN

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DECLARATION

"I **Damaris Wacu Nyingi** declare that this thesis is my original work and has not been presented for the award of a degree in any other university or any other award"

REG NO: A146/OL/NKU/24500/2014

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ABBREVIATIONS

BSFLM: Black Soldier Fly Larvae Meal

FAO: United Nations Food and Agriculture Organization

FCE: Feed conversion efficiency

GDP: Gross Domestic Product

IC: Indigenous Chicken

ICIPE: International Centre of Insect Physiology and Ecology

IDRC: International Development Research Centre of Canada

KALRO: Kenya Agricultural and Livestock Research Organization

Ksh: Kenya shilling

MOA: Ministry of Agriculture, Kenya

ABSTRACT

Kenya's poultry production is constrained by high production costs occasioned by the high price of protein ingredients such as fishmeal and soybean meal, hence the need to seek alternative sources of proteins in poultry feed. This study evaluated the live weight changes, feed conversion efficiency, and egg production and their quality in the Improved Kenyan Indigenous Chicken raised on the BSFLM as protein sources. Five dietary treatments were formulated with BSFL meal replacing both FM and SBM at different inclusion levels: 0% BSFLM, 25% BSFLM, 50% BSFLM, 75% BSFLM and 100% BSFLM. These diets met the nutritional requirements of a layer chicken. Fifty-five laying indigenous hens aged 31 weeks at the peak of production were obtained from the KALRO Naivasha poultry unit, where they had undergone genetic improvement. The chickens were divided into five groups, each with 11 birds, and allocated the five trial diets in a completely randomized experimental design. The chickens were individually placed in layer battery cages from where they were fed 200 g/bird/day of the experimental diets. The amount of feed taken by the birds, production of eggs, weight of the eggs, and live body weight were recorded weekly for 22 weeks. Egg characteristics were also determined. The finding of the study showed significant differences ($p < 0.05$) in average daily feed intake among the diets but changes in feed consumption were not consistent with increasing BSFL inclusion in the diet. Production of eggs was also affected by dietary BSF larvae inclusion, with diet D4 (100% BSFLM) having the highest laying percentage (84.2%) while the control diet had the lowest laying percentage (54.0%). Egg weight ranged from 57g in the control to 63 g in the D3 (75% BSFLM) layers. The highest egg yolk colour intensity (15) was for D4 (100% BSFLM) layers and the lowest was for control layers. The weight gain among the birds on diets containing BSF larvae was not significantly different. BSFL inclusion levels D3 (75% BSFLM) and D4 (100%BSFL) had the best return on investment. The results of this present study therefore demonstrate the potential usage of BSF larvae in improved indigenous chicken layer diets.

CHAPTER ONE: INTRODUCTION

1.1 Background

Indigenous poultry chicken makes up 80% of Kenya's poultry industry, which includes both indigenous and exotic chicken. (MOA, 2019). The poultry industry holds considerable role in providing quality protein (Mottet, A., & Tempio, G. 2017). Good animal nutrition is of great importance to successful livestock production. Essential amino acids for poultry diets are sourced from animals and plants. Fish meat and blood meal are the most often utilized animal protein ingredients, while plant protein sources include oil cakes and legumes (Van Huis *et al.*, 2013). Free-range chicken access insects naturally, therefore the insects have the potential to be used as substitutes for traditional proteins from animal and plant sources in animal diets (Charlton *et al.*, 2014). Studies have shown that insects are palatable and their nutritional content could replace soybean meal or fishmeal in animal feeds (FAO, 2014). The purpose of this trial was to determine the Egg laying percentage and nutritional value, and economic potential of using BSFL in the feeds of improved Kenyan indigenous chickens.

1.2 Problem statement

Poultry production is an efficient system with feed conversion rates that make it one of the most economically viable activities and important sources of human food. The global consumption of poultry products has increased over time, and this trend is projected to continue, particularly in developing countries. Growth in the poultry sector will result in corresponding demand for poultry feeds. However, the availability of chicken feed is limited by its high cost and scarcity of raw resources., particularly proteins which typically consist of animal and plant materials such as soya bean and fish meals.

The potential for substituting conventional protein ingredients with insects in compounded feeds for livestock and fish has been documented. Nevertheless, there is scarce information to guide the utilization of insect-based diets for optimum productivity in chickens.

1.3 Objectives of the Study

1.3.1 Overall Objective

This research aimed to investigate how including BSF larvae in the layers diet affects the laying performance of chicken. The goal is to determine if BSF larvae can be used as an alternate protein source for feeding indigenous chicken breeds in Kenya.

1.3.2 Specific Objectives

1. To assess the egg production of improved Kenyan indigenous layer chicken consuming diets containing varying amounts of BSFL meal.
2. To evaluate the egg characteristics of improved Kenyan indigenous layer chicken given diets containing different quantities of BSFL meal.
3. To determine the cost-effectiveness of substituting dietary fishmeal and soybean meal on improved Kenyan indigenous layer chicken.

1.4 Hypotheses

1. There are no significant differences in the production of eggs (%) of improved Kenyan indigenous layer chicken offered diets containing varying amounts of BSFL meal

2. There are no significant differences in egg characteristics of improved Kenyan indigenous layer chicken consuming diets with different levels of BSF Larvae meal or conventional protein sources.
3. There is no significant cost or benefit of replacing soya bean and fishmeal with different levels of dietary BSFL-improved Kenyan indigenous layer chicken.

1.5 Justification of the study

Poultry accounts for approximately eight percent of the agricultural GDP in Kenya (FAO, 2012).The versatility of the poultry industry is shown in the roughly 35,000 tonnes of meat and 1.6 billion eggs produced each year. . (ILRI, n.d.)

Nevertheless, the sector faces several constraints, including the shortage and the high cost of poultry feed. Feeds account for almost 60-70% of the production cost in chicken production. (Thirumalaisamy; G et al., 2016). While insects are the natural diets for birds, previous studies suggest that insect meals have comparable protein and fat content to the commonly used plant and animal sources that are expensive and in short supply (Makkar *et al.*,2014)., Information and practices on the use of insects- based products to optimize indigenous chicken performance is inadequately documented. The study assessed the usage of BSF larvae meal in diets of improved Kenyan indigenous chicken layers.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Poultry are domesticated birds kept for meat, eggs, or feathers. (Vaarst *et al.*, 2015). Traditionally poultry are kept in small flocks, scavenging for feed during the day (FAO, 2012).

Chicken are valuable source of animal protein for both low, medium, and high-income populations. They play a vital role in alleviating poverty, contributing to income generation, market involvement, and serving as a form of household insurance through the sale of birds. Mottet, A., & Tempio, G. (2017).

The population of indigenous chickens has shown a consistent increase over the years, as illustrated in Table 2.1. This could be a result of the expanding global population and urbanization, which has led to the intensification of poultry production, often in proximity to consumer markets (FAO, 2012). Poultry are an important part of the global food sector due to their efficient feed conversion efficiency compared to other animal species. Chicken are commercially kept in bigger numbers than any other type of poultry. Globally more than 50 billion birds are reared annually. This could be a result of the expanding global population and urbanization, which has led to the intensification of poultry production, often in proximity to consumer markets. (FAO, 2013).

Table 2.1 Kenyan indigenous chicken population

Year	Indigenous chicken Population
2010	24,538,906
2011	26,219,935
2012	27,967,976
2013	32,569,198
2014	33,088,442
2015	34,666,188
2016	36,578,441
2017	40,067,874
2018	42,791,309
2019	46,096,114

Source: (Ministry of Agriculture, Livestock and Fisheries Reports)

2.2 Poultry production systems

Poultry systems for production are classified according to scale of output, function, stock type, management, and profitability. There are three types of poultry systems based on flock numbers and input-output relationships; intensive, semi-intensive, and extensive/free range, (FAO, (2014), Veterinaria Digital, n.d.).

Intensive systems are based on specialized breeds for meat or the production of eggs, with standardized practices on housing, feeding, and disease control. The sizes of the flocks in the intensive system are characteristically in thousands, while the sizes in the semi-intensive system range from 50 to 200 birds (FAO, 2014). Intensive as well as semi-intensive poultry production is typically based on keeping the domestic chicken (*Gallus domesticus*). On the other hand, extensive or free-range management systems have different poultry species kept on the farm with variable flock sizes; chicken kept under this system have low capital input with low sustainable outputs. (FAO, 2014).

2.3 Production of eggs

Production of eggs is the main component of reproduction in healthy hens. Chickens begin laying eggs between the ages of 16 and 21 and continue to do so profitably for a duration of Sixty weeks. The number of eggs produced is influenced by several factors (internal and external) including breed, environmental factors, age, and nutrition. (Johnson, 2015, Hanusova et al., 2015, Lordelo et al., 2017)

2.3.1 Egg laying

An egg is defined as an oval or rounded body walled by a shell or membrane by which some animals reproduce, and from which the young hatches out after incubation for some time. (Webster Dictionary, 2019). The shell is a hard outer covering of the egg which is composed of calcium carbonate (Figure 2.1). The shell is permeable allowing for the diffusion of gasses. Beneath the shell are outer and inner shell membranes, whose role is to protect the egg contents from bacteria and loss of moisture. The egg's clear fluid, known as albumen, consists mainly of water and 10g of proteins per kilogram, with the additional presence of fat and carbohydrates, while the yolk constitutes 33% of the liquid weight. (Virginia Cooperative Extension, n.d.)

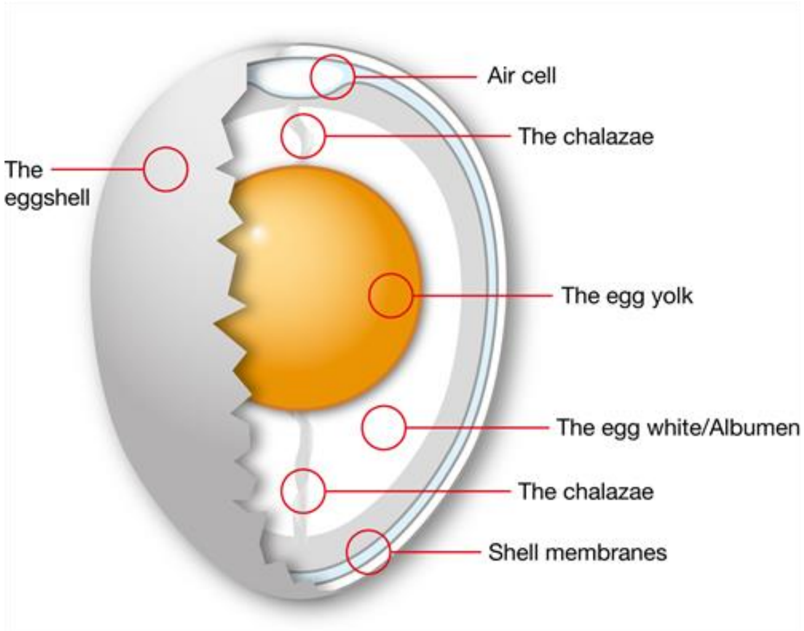

Figure 2. 1 Structure of an Egg

(Source: HEDEGAARD foods, http://en.eggs.dk/the-egg/structure-of-the-egg.aspx

2.3.2Egg productivity and quality

Production of eggs can be measured using two methods: Hen-day and hen-housed systems. 'Hen day' is commonly shown as a percentage, and is derived by adding the total number of chickens alive each day and then computing the quantity of eggs produced during that time. It usually indicates the production ability of the chicken in the house. On the other hand, 'Hen-Housed' is usually indicated in numbers. From a profit perspective, it can be misleading because it shows how well the birds are laying but ignores factors like egg size and egg yield, which determine how much revenue is generated from eggs.

The term "hen-housed" describes the total quantity of eggs laid by a flock of hens during a given time frame. , often measured on a daily, weekly, or monthly basis. It represents the overall egg production output from the entire flock of hens during a set time frame.

On the other hand, "hen-day" refers to the quantity of eggs laid by a single hen in a given day. It is a measure of individual hen productivity and is often used to assess the average performance of hens within a flock. Hen-day production can be useful for evaluating the efficiency and health of individual hens in a group.

Using egg weight save for the egg numbers leads to a better comparison of flocks. The average egg weight is determined by weighing samples of the eggs produced.
Certain characteristics are used to define both the internal and exterior properties of an egg; the traits are influenced by several variables ; Various traits are employed to separate both the internal and external attributes of an egg, and these characteristics can be influenced by various factors; including production systems (Samiullah et al., 2017), Age of bird (Roberts, 2013) Age of the eggs (Perić et al., 2017), and the environment (Sharma et al., 2022).

The internal egg qualities are the albumen height (millimeters) and the Haugh Unit; The Haugh unit is a computed value using the egg weight and the height of its albumen. It is projected that the Haugh Unit value is uniform for eggs of similar appearance irrespective of their size. The egg yolk quality is indicated by its color intensity, the colour varies from a very pale to deep orange depending on the nutrition of the hen because pigments in the food are transferred directly into the colour of the egg yolk. The Roche Scale measures the egg yolk colour, using a Fan with 12 shades of yellow colour comparable to the egg yolk (Figure 2.3). The external egg characteristics considered are the eggshell quality in terms of the cuticle cover, shell strength, and eggshell ultrastructure. (Roberts, 2013).

In the chicken business and commerce, it is feasible to analyse egg yolk colour through visual inspection using the La Roche scale instead of quantifying carotenoid concentration expressed as beta-carotene. Visual inspection gives rapid and clear information more closely matching the colour of the egg yolk as perceived by the senses. (Bovšková et al., 2014)

Figure 2.2 Yolk Colour Fan (Source: ORKA Food technology

Factors affecting Egg production

The production cycle of a hen lasts over a year and may be determined by several features such as type of breed, management, environmental conditions, body weight, and feed quality (Shcherbatov & Shkuro, 2021).

(a) Breed

Chicken breed influences the production of eggs. Commercial layer breeds e.g. the White Leghorn, Bovangoldline, Sussex have high production traits with an average of 250-300 eggs perhen per year while indigenous chicken has an average of 34-80 eggs per hen per year (Lemlem & Tesfay, 2010, Kenya Agribusiness and Agroindustry Alliance, n.d., (FAO, 2003)., At the Kenya Agricultural Research (KALRO) facilities where this study was conducted, the production of improved indigenous chicken has been improved to about 250-280 eggs/hen/year. (KALRO, 2014).

(b) Management

For optimum production of eggs, proper flock management is crucial, including good housing, disease control, proper lighting, laying nests, and feed management.

Production of eggs is stimulated by the light of day; artificial light can be used to intensify the laying period. Two to three hours of artificial lighting can improve the production of eggs by 20 to 30 percent (Merck Veterinary Manual, 2023,). Artificial lighting ought to be maintained for maximum production of eggs in structures where laying birds are not accessing natural light

(c) Environment

Environmental conditions affect the laying of eggs (Talukder *et al.*, 2010; Gerzilov *et al.*, 2012). The chicken house should be constructed in line with local environmental conditions to avoid exposing the chicken to rain, direct sunlight, strong wind and heat cold, and weather variations (FAO, 2003).In hot and humid climatic conditions, open housing should be used to allow proper ventilation which is critical for the economic production of eggs.

(d) Age

Chicken produce eggs for a year from approximately 21 -72 weeks of production old (FAO, 2003), towards the end of the egg-laying period, production of eggs decreases and there may be a rise in the frequency of thin-shelled eggs. (Lee *et al.*, 2016). Internal egg qualities are affected by age of the laying birds (Dikmen et al., 2017)

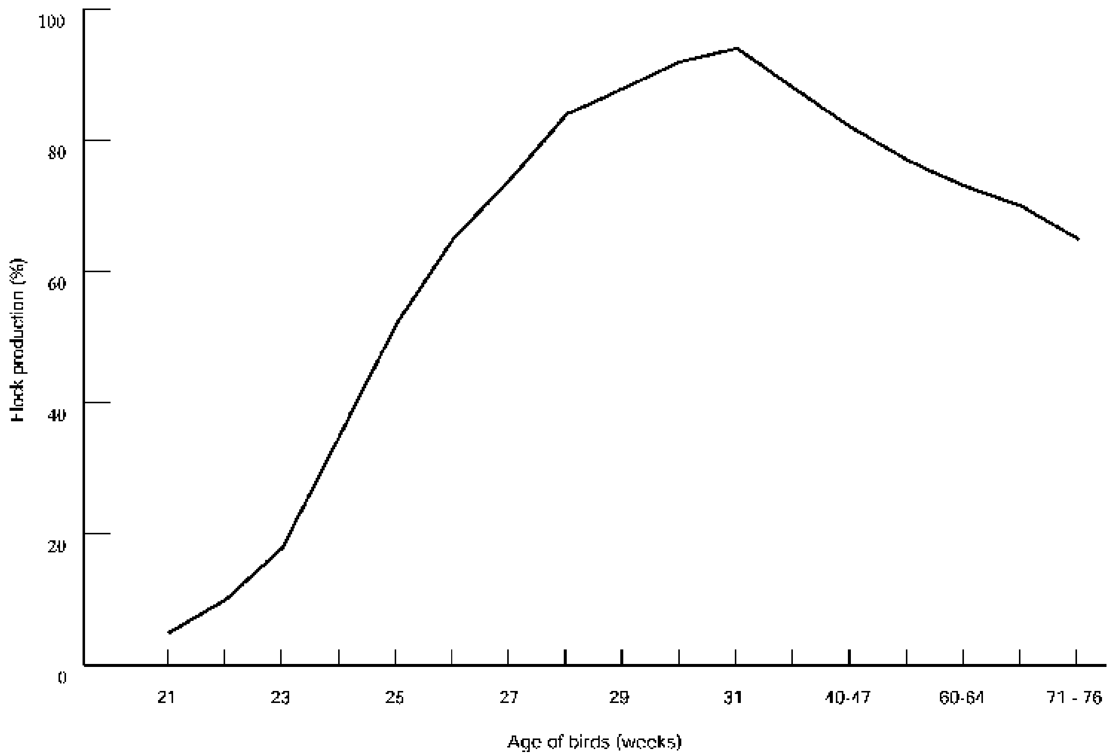

Figure 2. 3 Standard laying curve of chicken (Source: (FAO, 2003)

(e) Body weight

The live body weight of a hen at the commencement of lay influences the yolk size, and therefore the overall egg weight. The ideal weight through the laying period should be 1.5 kg, but this differs between breeds. Underweight and overheavy birds do not lay eggs at the same rate as normal-sized birds. Good husbandry and feeding are critical to achieving the ideal weight of a chicken. (FAO, 2003)

(f) Nutrition

Nutritional factors affecting egg quality are also dependent on feed intake, hence feed management practices. Chicken prefers coarse particle-sized feeds; hence feed distribution is important during the day to make sure the birds consume the fine feed particles which are usually minerals and vitamins. (Ege et al., 2019)

2.4 Poultry Nutrition

Feeding and digestion

Nutrition involves supplying feeds with nutrients that meet the animal's needs for growth, maintenance production, etc. For cost-effectiveness, the supply of nutrients should be on a least-cost basis, and without any wastage.

2.4.1 Nutritional requirement of chicken

When formulating rations, the nutrients considered are energy, protein, fat, vitamins, and minerals. Apart from water, all other nutrients are supplied by the ingredients constituting the diet.

Protein is a key nutrient in poultry diets beneficial in sustaining and repairing tissues to support growth. (Champrix, n.d.). Different breeds may require different levels of protein in their diet to support growth, maintenance, and production. Production is severely compromised if quality protein levels in the diets are not provided. Indigenous chicken requires at least 160g/kg for growth and maintenance (Kingori *et al.,* 2003). Proteins are provided from animal and plant sources which vary in amino acid profiles. Animal proteins are generally balanced in amino acids than plant proteins but are more expensive. It is important to use both animal and plant protein sources to achieve quality at a reasonable cost.

A poultry producer should pay attention to the quality and formulation of the diet bearing in mind that feed cost comprises 65 to 75% of the cost of producing eggs (, (Feed Formulation," n.d.). It is significant for a laying bird to have a constant supply of nutrients based on its nutritional requirement (FAO, 2013).

Protein is a major requirement in chicken for growth and production of eggs. The amino acids are the fundamental building components of structural and metabolic proteins, as well as enzymes. Sufficient dietary amino acid supply is as body proteins are continuously produced and degraded in the body. A total of 22 amino acids are needed for body proteins, some are synthesized by the bird (non-essential), while essential amino acids are provided in the diet. An adequate amount of non-essential amino acids should be supplied to avoid the conversion of essential amino acids to non-essential acids. (He, Li, & Wu, 2021) Various studies have shown that dietary protein affects egg size and weight (Wang, Xiaocui (2015,)

Phosphorus and calcium are necessary for the development of eggshells. (Sinclair-Black et al., 2023, Skřivan et al., 2016) while dietary fatty acid composition directly affects egg yolk fatty acid content (Sultan et al., 2015, Keum et al., 2018), The recommended daily intake of calcium in laying birds is 3·25 g per bird (NRC, 1994). The calcium carbonate content of a chicken eggshell typically ranges from 93% to 97% and is influenced by several factors such as animal genotype, age, laying hens' housing system, and mineral nutrition. (Kristl et al., 2019)

Lack of vitamins such as Vitamin A, D, B2, choline, and folic acid in poultry diets may result in decreased production of eggs and thin-shelled eggs. Vitamins are supplied through the addition of vitamin premixes during poultry feed formulation.

2.4.2 Efficiency of food utilization in laying birds

The following indices are used to measure feed utilization efficiency:

(a) Feed Conversion Ratio (FCR);

This is the ratio of the feed consumed and the egg mass, it also considers the feed consumed, and the total weight of egg and egg production.

$$FCR = \frac{FC(feed\ consumption)}{NEP(number\ of\ eggs)}$$

(b)Net Feed Efficiency index $NFE = \frac{(EM+BW)100}{FCs}$ where;

EM = Average egg weight (g)

BW = Average body weight gain (g)

FC = Average Feed consumption/hen (g)

NFEI value of 45 and above is desirable.

(c) Egg: Feed price ratio

It can be utilised to calculate the income from eggs versus feed expenditures. A ratio of 1.4 is preferred.

$$Feed\ price\ ratio = \frac{Total\ value\ of\ egg\ produced}{total\ feed\ value}$$

2.5Use of insects in animal feeds

Insects are a prospective viable food resource in animal diets due to their high dietary value and widespread distribution. Insects such as grasshoppers, crickets, termites, aphids, beetles, fleas, bees, wasps, and ants are natural feeds for free-ranging chicken. The insects are rich in protein ranging from 40 to 75 percent. (Van Huis *et al.*, 2013). The insects such as BSFL are also rich in other ingredients (Table 2.3) A review by Moreki *et al.*, (2012) indicated seasonal variability for different insects in Botswana that are important for smallholder poultry production.

Table 2.2 Nutritive content (% DM) of some insects

Constituents%	BSFL	Locust	House	Silkworm	Fishmeal	Soymeal
Crude protein	42.1	57.3	63.3	60.7	70.6	51.8
Lipids	26.0	8.5	17.3	25.7	9.9	2.0
Calcium	7.56	0.13	1.01	0.38	4.34	0.39
Phosphorus	0.90	0.11	0.79	0.60	2.79	0.69
Ca:P ratio	8.4	1.2	1.3	0.6	1.6	0.6

Source: Makkar *et al.*, (2014)

Raising insects on organic waste, such as vegetables and domestic refuse, can make them an inexpensive and locally available resource, resulting in a potential 60% reduction in waste. Public concerns about feed safety from animal-origin foods have intensified due to concerns on chemical contamination (for example dioxin contamination), food-borne infections, veterinary drug residues, and microbial resistance to antibiotics. The persistence of chemicals such as pesticides and antibiotics in the foods is of specific concern for insects used as animal feeds. Industrial toxins are potential contaminants but dependent on the rearing method and preservation but the processing of insects into meals reduces the chemical contamination. (Charlton *et al.*, 2014)

There are possible unidentified risks of allergens in insects such as Tropomyosin, which is existent in many insect species and is responsible for allergies, (Charlton *et al.*, 2014). A study exploring the safety of insect larvae reported that the levels of chemical contamination were lower than the allowed maximum allowable limits by the EU Commission and the WHO. Cadmium, a highly toxic carcinogenic chemical was of concern in housefly samples examined in the study (Charlton *et al.*, 2014)

2.6 Black Soldier Fly (*Hermetia illucens*)

Black soldier flies are found naturally around piles of manure from cattle poultry and pigs. Black Soldier fly (*Hermetia illucens*) is a widespread fly of the family Stratiomyidae. The adult Black Soldier is a 15–20 mm long, black, non-biting fly with dark wings. The second abdominal segment of the female has two transparent spots, and her abdomen is reddish; the male's is bronze. The oval eggs are 1 mm long in size. Freshly placed ones are light yellow, but they eventually turn dark. (University of Florida, n.d.)

Figure 2.4 Black soldier fly adult and Larvae *(Source: Albertaaquaponics (2019)*

The larvae of BSF are plump, and fairly flattened, with a minute, yellowish blackhead or creamy white, when freshly hatched its length is about 1.8 mm long. There are six stages in the larva's development, with reddish-brown marking the sixth. Although some can grow to a length of 27 mm, adult larvae are typically 18 mm long and 6 mm wide. The larvae require a humid environment to thrive. The fly normally breeds in latrines, unpleasant managed compost, and in poultry manure. Black Soldier larvae are scavengers, thriving on various types of decaying organic matter, e.g. plant refuse, carrion, and manure. (Maglangit, Alosbanos, & Akeed, 2021)

Table 2.3 Difference in amino acids content of BSFL raised on different substrates

	BSF Larvae Substrate	
Essential Amino Acids	Beef	Swine
Methionine	0.9	0.8
Lysine	3.4	2.2
Leucine	3.5	2.6
Isoleucine	2.0	1.5
Histidine	1.9	1.0
Phenylalanine	2.2	1.5
Valine	3.4	2.2
l-Arginine	2.2	1.8
Threonine	0.6	1.4
Tryptophan	0.2	0.6

Source :(Newton *et al.,* 1977*)*

In a study by Muin *et al.,* (2012) on the nutritional quality of BSF pre-pupae, it was 51.39% CP, 17.02% EE, 9.35 gkg ash, and 16.76% fiber, 96.47mg/g essential and 126.38mg/g non-essential amino acids and eight components of fatty acids. Different studies have suggested a positive effect of BSFLM on feed intake (Mat *et al*., 2022, Mwaniki, 2019) Widjastuti *et al*., (2014) reported that the application of BSFLM in quails had a substantial effect on feed consumed, FCR and egg quality but no influence on production of eggs.

CHAPTER THREE: MATERIALS AND METHODS

3.1 The Study site

The study was done at KALRO - Naivasha Poultry Research Unit. The Research Centre is located near Naivasha town (0°43’S, 36°26’E) in Nakuru County, Kenya. Which is about 154 km northwest of the capital city Nairobi. The area has an annual average rainfall of 677mm, 21°C on average daily temperatures, and a Relative humidity is 62%.

KALRO is a part of the Ministry of Agriculture, Livestock, Fisheries, and Cooperatives. Its mandate is to coordinate, streamline, promote, and control research in Kenya related to crops, livestock, genetic resources, and biotechnology. It also includes overseeing research related to crops and animal diseases. Equitable access to research information, resources, and technology is a priority, along with the promotion of the practical application of research findings and technology in the field of agriculture. (KALRO, n.d.)

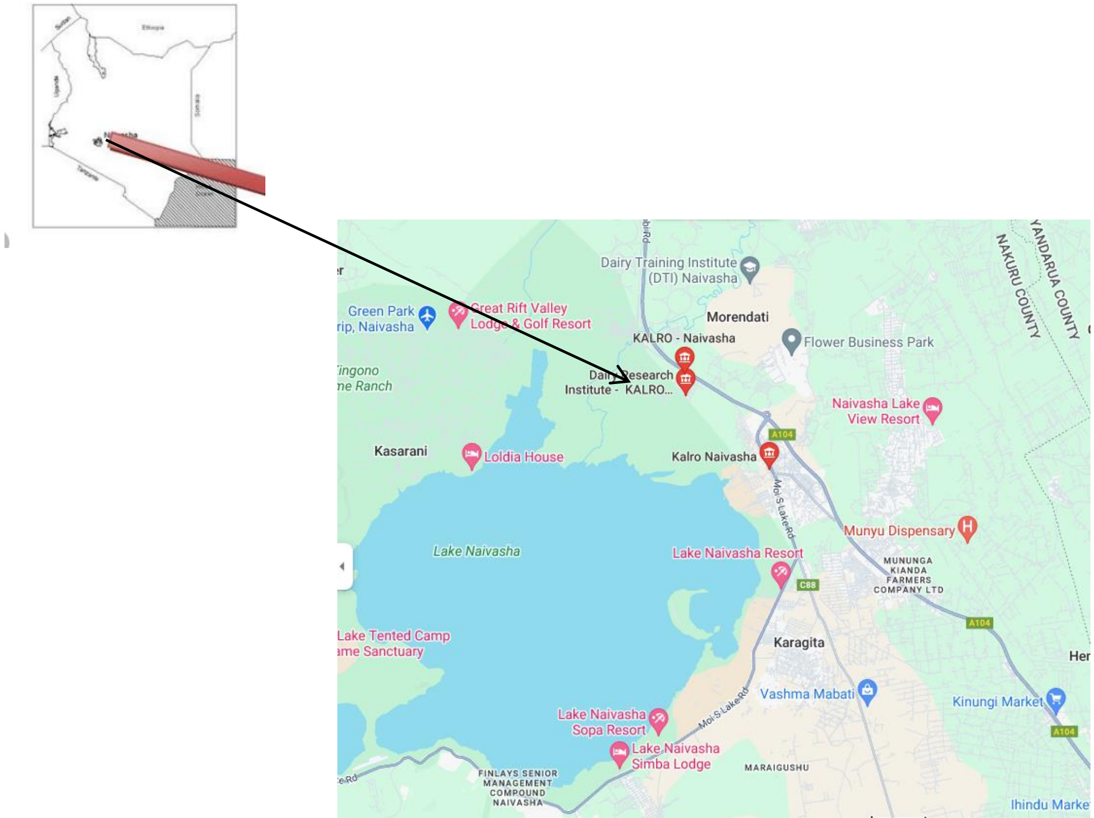

Figure 3.1: Map of study area showing KARLO in Naivasha

3.2 Experimental diets

Five diets were formulated once with varying amounts of soybean, fishmeal, and BSFL meal (Table 3.1) constituting 16 % Crude Protein (CP) and 2850 Kcal/kg of Metabolizable energy (ME) and as per NRC (1994) specifications for layer birds. BSFL meal was incorporated into diets at a rate of 25%, 50%, 75%, and 100% to replace soybean and fish meals. The BSFL was obtained after sterilization and drying from Synergy Limited located in Machakos County, Kenya. Where they had been raised in a combination of household and solid waste (any type of garbage, trash, refuse, or discarded material). Other feed components were obtained locally from feed millers.

Table 3.1 Experimental diet composition

Ingredient (kg)	C	D1	D2	D3	D4
Maize grain	49.1	46.95	46.08	45.2	46.82
Wheat pollard	29.11	28.94	29.08	28.2	24.91
Bone Meal	0.39	2.00	0.38	0.45	0.01
Soybean meal	7.83	8.53	4.96	3.60	0.00
Fish meal (Omena)	7.51	3.07	2.59	0.17	0.00
BSFL meal	0.00	5.00	10.00	15.00	20.00
Di-calcium phosphate	1.27	1.42	2.32	2.87	3.46
Limestone	4.44	2.81	4.06	3.89	4.18
Layers' Premix[1]	0.35	1.27	0.52	0.62	0.62
Protein (%) replaced with BSFL	0.00	25.00	50.00	75.00	100.00

3.3 Experimental birds and design

The improved indigenous chickens used in this study were obtained from a flock at KALRO, Naivasha Center. This breed of chicken was developed from the local indigenous chicken for improved growth rate and production of eggs (KALRO, 2014). The improved indigenous chicken has an average weight of 2.5kg for males at sexual maturity of 5 months and 2 kg for females at first laying. The average production of eggs is estimated at 250 eggs/hen in a productive period of one year. Fifty-five (55) laying chickens aged 31 weeks at the peak of production, were used for the experiment, the trial utilized a fully randomized design, with each diet administered to 11 bird replicates. The hens were randomly placed in individual layer battery cages measuring 40 cm by 45cm by 40 cm from where they were freely accessing individual feed and water. The birds were allowed one week to acclimatize to the dietary treatments, followed by a 22-week data collection period where treatment diets were offered *ad libitum* or at least 200 g/bird/day. All the chickens underwent routine vaccination, health, bio-security measures, and husbandry practices at KALRO.

Figure 3.2 Chicken battery cage (40 x45cm x 40cm)

3.4 Chemical Analysis of Feeds

Samples of raw feed materials (BSFL, soybean meal, and fishmeal) and the formulated experimental diets were examined for DM, ash, CP, EE, and CF using the Association of Official Analytical Chemists (A OAC, 1990) methods.

3.4.1 Determination of true Metabolizable energy for BSFLM

True Metabolizable Energy (TME) is the dietary energy available to the chicken, which is the gross energy (GE) of consumed feed less the GE of droppings. TME for BSFL was determined using eight (8) adult cockerels that were randomly separated into two groups: one fed on a BSF larvae meal and control on a similar amount of glucose. The standard procedures outlined by Latshaw and Freeland (2008) and Farrell, (1974) were employed for this study. The cocks were housed individually in cages and a metallic tray wrapped with a polythene sheet was placed beneath each cage to collect the droppings. The cocks underwent a 24-hour fasting period with unrestricted access to water to ensure complete clearing of their digestive system. Each test diet of 40 grams was force-fed (using a feeding tube) Chitty and Monks (2018) to eight (8) individual cocks, for seven days, Excreta was collected daily 24 hours after feeding, and placed in sealed zip-lock bags and stored at -20°C temperature. To determine Metabolizable energy (ME), samples of one gram of the test diets and a corresponding quantity of the stored excreta was completely combusted in a Bomb Calorimeter. True Metabolizable Energy was calculated from Gross energy in feed and excreta and feed input (g).

3.5 Data collection methods

3.5.1 Feed Intake

Daily feed offered and leftovers were measured to estimate the average daily feed intake (ADFI) for duration of the study (22 weeks). ADFI was calculated as total feeds allocated less total daily leftover feed.

3.5.2 Live Weight

The initial live weight of the chicken at the beginning of the trial was measured and thereafter, the chicken was weighed weekly using a digital scale (SHIMADZU-TXB6201L) to monitor weight change throughout the experimental period.

3.5.3 Feed conversion ratio (FCR)

This ratio was computed using daily feed consumption and daily egg weight or quantity of eggs, representing the relationship between feed intake and egg weight or egg numbers.

$$\text{FCR} = \frac{\text{Feed consumed(g)}}{\text{Number of Egg Produced}}$$

3.5.4 Production of eggs

Eggs were collected in clean trays, with the quantity recorded per cage for each treatment. All labelled eggs were then held at room temperature to measure their properties.

3.5.5 Determination of Egg Quality

A digitized Vernier caliper was used to measure the egg's height from bottom to top as well as its width in the center. The shape index was computed by multiplying the width to the length by 100.. A weighing scale was used to measure the eggshell weight with an accuracy of $\pm$0.01g. Eggshell thickness was measured using a Vernier caliper on eggshells from different egg points i.e. at the bottom, top, and middle. As shown in formulas 1, 2, and 3, the eggshell ratio was derived by multiplying the egg weight by 100 and dividing the eggshell weight.

$$1.\ \text{Shape Index}\ \% = \frac{\text{Egg width(mm)}}{\text{Length(mm)}} \times 100$$

$$2.\ \text{Egg shell Thickness} = \frac{\text{Bottom piece} + \text{Centre Piece}\ + \text{Top Piece}}{3}$$

$$3.\ \text{Eggshell ratio\%} = \frac{\text{Eggshell weight(g)}}{\text{Egg weight (g)}} \times 100$$

Egg yolk colour intensity was assessed using the Roche Colour Fan described in Section 2.3. The yolk and the albumen were separated and weighed separately. A digital Vernier caliper ruler was used to calculate the albumen height, yolk diameter, and yolk height to the nearest 0.01 mm. (Figure 3.2). Internal quality characteristics were determined using the yolk ratio, yolk index, yolk/albumen ratio, and Haugh Unit as per the following formulae:

$$1.\ \text{Yolk ratio\%} = \frac{\text{yolk weight(g)}}{\text{Egg weight (g)}} \times 100$$

$$2.\ \text{Yolk Index\%} = \frac{\text{yolk height(mm)}}{\text{yolk diameter (mm)}} \times 100$$

$$3.\ \text{Yolk albumen ratio\%} = \frac{\text{Yolk weight (g)}}{\text{Albumen weight (g)}} \times 100$$

$$4.\ \text{Haugh Unit} = 100 \times \log_{H+7.57-1.7}\, w0.37$$

Where:

H - Albumen height (millimeters);

W - Average egg weight (grams)

Figure 3.3 Measuring egg yolk diameter

3.5.6 Economic evaluation of feeding improved Kenya indigenous chickens with diets containing BSFLM.

To assess the economic impact of substituting BSFL with conventional protein components in layer diets, the CBR and RoI parameters were used. The cost-benefit ratio (CBR) is the ratio of income to production costs. A cost-benefit ratio of greater than one (1) indicates that the project's advantages outweigh its expenses, and vice versa. The Return on investment (ROI) is a measure that assesses whether an investment has generated a profit or loss about the capital invested. The project under consideration will generate a greater return on investment with a higher RoI value. (De-pach, 2012). Feeds, labor, veterinary services, water, housing, and feeders were some of the production inputs cost. Since all other expenses were assumed to be constant across all treatments, only the cost of the feed was taken into account. The price of the feed ingredients and the amount added to the diets were taken into account when calculating the feed expenses. Proceeds obtained from the sale of eggs by the end of the experiment represented all the financial benefits gained from the study. Proceeds obtained from the sale of eggs by the end of the experiment represented all the benefits gained from the study.

3.6 Data analysis

One way analysis of variance (ANOVA) was implemented on data on egg production and characteristics. Feed intake and weight, significant means of all measures were separated using the Tukey's multiple comparison method at $p<0.05$. All the statistical analyses for all the parameters were determined using R Statistical Software Version 3.3.2.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Nutritional analysis of BSF larvae meal

The proximate analysis of formulated diets is detailed below in Table 4.1.

Table 4.1 Proximate composition of treatment diets (*on DM basis)*

COMPOSITION	**0 BSFLM**	**25 BSFLM**	**50 BSFLM**	**75 BSFLM**	**100 BSFLM**
DM	89.6	90.1	89.6	89.6	89.2
Crude Protein	16.7	17.5	17.0	16.6	16.7
Ether extract	3.5	5.5	7.6	6.8	6.4
Ash	7.9	8.6	11.5	9.8	9.7
NFE	66.9	63.4	57.9	60.8	59.2
ADF	38.3	55.2	45.3	51.3	53.3
NDF	11.2	15	9.4	3.9	13.5
ME	2840.5	2857.1	2863.2	2867.2	2869.1

NFE = Nitrogen Free extract, ADF = Acid Detergent Fiber, NDF = Neutral Detergent Fiber, ME=Metabolizable Energy

The BSFL meal used in this research had a crude protein (CP) content of 43.9%, which compared well with the CP of 40– 56% reported in prior studies by Onsongo *et al.* (2018) and Al-Qazzaz *et al* (2016). The slight variations in the CP content of BSFL reported in various studies are attributed to the substrate used for insect growth (Spranghers et al., 2017), and the stage of harvesting has an impact on the protein content of the larvae feed as well; it decreases as the larvae get older. (Liu et al., 2017).

In comparison, the raw soya bean meal and fishmeal obtained from the market for the purpose of this study had CP of 49.4%and 42.7%, respectively. The CP for the soya bean meal was within the expected range of 40-44% of regular or dehulled soybean, but the fishmeal was considered low when compared to the 60% CP recommended for quality fishmeal (FAO, 2019). The low protein content of the fishmeal obtained in the market has been attributed to possible adulteration. (Nalwanga *et al.,* 2009). This affirms the need to evaluate raw materials obtained from the market for nutritive content before incorporation into animal diets.

Proximate analysis of the diets formulated for this study indicated that the nutrient composition of all five diets was within the commended levels for laying chicken (NRC, 1994). The CP content of the diets ranged from 16.7% in the control diet (without BSFL) to 17.7% in diet D1 (25% BSFL inclusion level) (Table 4.1). Dietary CP content was within the minimum requirement of 16% for laying chicken. The D2 diet (50% BSFL inclusion level) had the highest lipid and mineral contents as indicated by the ether extract (EE) of 7.6% and ash contents of 11.5% respectively.

4.2 layers Performance parameter

Table 4.2 below presents the outcomes of substituting soybean meal and fish meal with BSFL in Indigenous layer chicken rations, focusing on Feed Intake, Weight Change, and Laying Performance.

4.2.1 Feed Intake

Feed intake was highest in layers offered diets containing 25% BSFL l (D1), followed by the group on 100% BSFL (D4) which did not differ statistically ($P>0.05$). The lower feed intake (g) was observed in layers offered 75% BSFL (D3) which was not significantly different ($p<0.05$) from layers on 0% BSFL. The outcomes of this study suggest that the feed intake of the five diets was significantly different, but this was not affected by the addition of BSFL in the rations (Table 4.2). The addition of BSFL had no effect on palatability. The findings are in agreement with other studies carried out using different chicken breeds (Mwaniki *et al.*, 2018; Al-Qazzaz *et al.*, 2016; Ruhnke *et al.*, 2018).

Table 4.2 Performance of Indigenous layer chicken on diets containing varying levels of BSF larvae meal.

Parameters measured	0% BSFLM	25% BSFLM	50% BSFLM	75% BSFLM	100% BSFLM	p-value
Initial weight (g)	2012.73 ± 66.58^{a}	2027.55 ± 52.28^{a}	1910.64 ± 60.02^{a}	2083.73 ± 53.63^{a}	1971.80 ± 62.51^{a}	0.328
Final weight(g)	$1795.3\ 4\pm 75.42^{a}$	2082 ± 1034.80^{b}	2061.82 ± 73.45^{b}	2287.28 ± 90.23^{b}	2206.70 ± 82.54^{b}	0.001
Weight change (g)	-217.36 ± 28.41^{a}	54.45 ± 23.31^{b}	151.18 ± 24.85^{bc}	203.55 ± 19.28^{bc}	234.90 ± 29.84^{c}	0.001
Laying (%)	54.00 ± 2.40^{a}	71.00 ± 2.20^{b}	80.20 ± 1.90^{c}	74.70 ± 2.10^{b}	84.20 ± 1.70^{c}	0.001
Egg weight (g)	57.32 ± 0.32^{a}	59.69 ± 0.20^{b}	61.78 ± 0.22ab	62.63 ± 0.25^{ab}	61.76 ± 0.25^{ab}	0.001
Egg mass (g/day)	28.365 ± 0.74^{a}	38.32 ± 0.73^{b}	46.48 ± 0.67^{c}	44.84 ± 0.73^{c}	48.43 ± 0.61cd	0.001
ADFI (g/day)	105.64 ± 1.06^{a}	112.63 ± 0.96^{b}	107.33 ± 0.93^{a}	104.71 ± 0.77^{a}	112.10 ± 0.88^{b}	0.035
Feed conversion ratio (g/g)	3.72 ± 0.27^{a}	2.94 ± 0.15^{b}	2.31 ± 0.05^{b}	2.34 ± 0.04^{b}	2.31 ± 0.05^{b}	0.041

Within rows, means followed by different uppercase letters differ significantly (p< 0.05). BSFLM- BSF larvae meal, FM- Fish meal, SBM- soybean meal, 0% BSFLM (control) (100% FM & SBM + 0% BSFLM), 25% BSFLM (75% FM & SBM + 25% BSFLM), 50% BSFLM (50% FM & SBM + 50% BSFLM), 75% BSFLM (25% FM & SBM + 75% BSFLM) and 100% BSFLM (0% FM & SBM +100% BSFLM).

4.2.2 Food conversion ratio

The quantity of feed taken per egg weight produced is known as the feed conversion ratio, or FCR, and it is displayed in Table 4.2. Diets without BSFL had the highest FCR of 3.72. The FCR decreased with increased BSFL inclusion levels up to BSFL (D2). The FCR of the five diets was different significantly (P <0.05), but there was no significant difference in birds fed on diets with 50%BSFL, 75% BSFL (D3), and 100% BSFL (D4). These findings agreed with earlier studies by Mwaniki et al., (2018) and Al-Qazzaz et al, (2016) which showed that FCR increased with inclusion levels of BSF larvae.

4.2.3 Live Weight

The mean weight of chicken in the five groups was not significantly different at the start of the experiment at 32 weeks of age (p>0.05) as presented on Table 4.2. However, by 52 weeks, live weight gain was significantly different (p<0.05) with hens consuming the control diet (C) having a mean weight loss of -217.36 g, while all birds on BSFL gained weight with increasing amounts of BSFL in the diet. Al-Qazzaz *et al.*, (2016) reported different effects of BSFL on live weight in chickens with inclusion of BSFLM. This increase in live weight can be attributed to an improved feed conversion ratio with the inclusion of the BSFLM. BSFL has high fat content (ether extracts) supporting weight gain and reducing digestibility. Fats increase the energy content of feeds, reduce feed intake by slowing digestibility, and consequently lower the FCR.

4.2.4 Production of eggs

Production of eggs drifted over time is presented in Figure 4.1. Hens on diets containing BSFL maintained or increased the production of eggs from 32 weeks of age to 52 weeks, but by contrast, the laying percentage of hens on the control diets reduced the production of eggs over the same period.

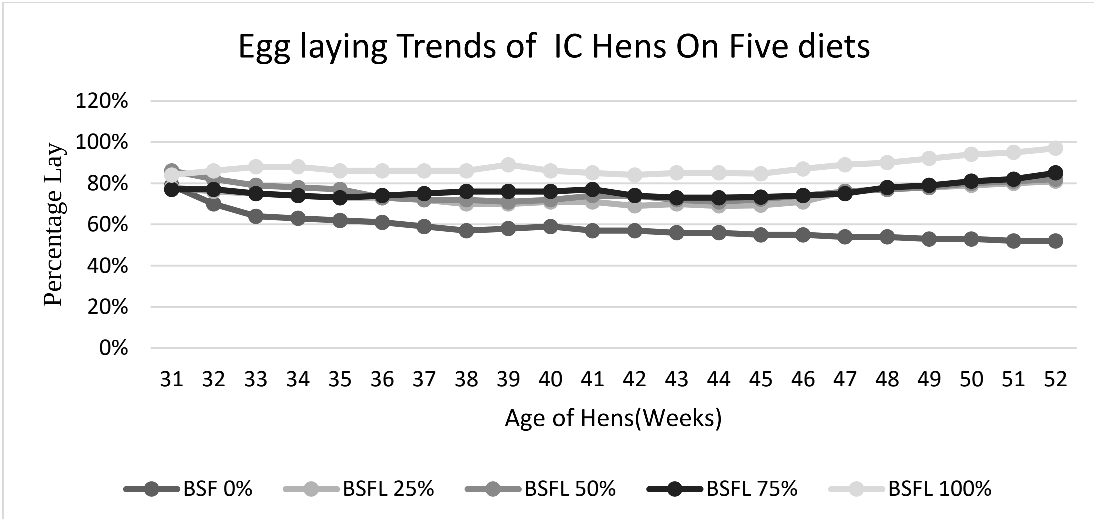

Figure 4.1 Laying curves for hens on feeds containing varying inclusion levels of BSFLM

Chicken-given diets with BSFL had increased egg production compared to those on the control or D0. All hens on diets with BSFL had higher egg-laying percentage than the group without dietary BSFL. Production of eggs increased from 54.0% in the birds consuming the control diet to 84.2% in those consuming diets with 100% BSFL inclusion D4. Production of eggs in the five diets was significantly different (P<0.05). However, there were no significant differences (p>0.05) in the laying percentage for the hens on 100% BSFL inclusion (D4) and 50% BSFL inclusion (D2) and also between 25% BSFL (D1) and 50% BSFL (D3) diets. Overall, the findings compared with a study by Al-Qazzaz*et al.*, (2016) who reported that the addition of BSFL meal inlayer diets significantly increased the production of eggs with the highest hen day production of eggs observed in the BSFL at 25%. However, a different observation was made in a study by (Ruhnke *et al.*,

2018) where there were no significant differences in the production of eggs with or without the inclusion of BSFL.

4.2.5 Egg Weight/Mass

Significant differences in egg weights were observed among the five treatments (P<0.05). Hens on diets with BSFL produced significantly heavier eggs than those from the control diet. Though, there were no significant differences (p>0.05) in egg weights for the hens on 100% BSFL inclusion D4, and 50% BSFL inclusion D2. Similarly, there were no significant differences (p>0.05) in egg weights for hens consuming 75% BSFL inclusion D3, and 50% BSFL inclusion D2. The conclusions of this investigation contradict with earlier studies by Ruhnke *et al.*, (2018) which suggested a significantly low egg weight in Isa brown hens offered diets containing a minimal amount of BSFL larvae meal (1.7 grams BSFL/ hen/ day).

In general, egg Mass intensified with increased BSFL levels in the diets. Eggs Mass from the control diet was the lowest at 28 g of egg/g of feed followed by the Egg Mass of the 25% BSFL inclusion D1 Diet at 38g of egg/g of feed, while the 100% BSFL inclusion D4 diet markedly higher Egg Mass at 48.43g/g of feed. (Table 4.4). These variances were significantly different (P<0.05) except between eggs on 50% BSFL inclusion D2 and 75% BSFL inclusion D3 diets. The increase in egg mass with increasing BSFL in the diets may be associated with increasing dietary fat from BSFLM. Al-Qazzaz*et al.*, (2016) stated that high ME had positive effects on egg weight.

4.3 Egg quality characteristics

The effect of replacing SBM and FM with BSFL meal on the improved indigenous chicken egg characteristics is presented in Table 4-3.

Table 4.3 Quality characteristics of eggs on five diets containing varying inclusion levels of BSFL meal

Parameters measured	0% BSFLM	25% BSFLM	50% BSFLM	75% BSFLM	100% BSFLM	p-value
Yolk colour	3.20 ± 0.38a	11.13 ± 0.17b	12.21 ± 0.16c	13.54 ± 0.16c	15.00 ± 0.14d	0.001
Haugh Unit	76.00 ± 3.37a	90.53 ± 3.78b	89.17 ± 4.53b	91.42 ± 4.53b	91.80 ± 5.42b	0.001
Yolk/Albumen ratio (%)	84.52 ± 23.52b	72.32 ± 5.04b	69.06 ± 4.73ab	65.16 ± 5.99a	68.44 ± 4.90a	0.001
Yolk Index (%)	33.04 ± 0.70	38.54 ± 0.77	36.62 ± 0.79	39.34 ± 0.82	37.08 ± 0.57	0.114
Yolk ratio (%)	23.33 ± 1.20a	24.54 ± 0.72a	25.19 ± 1.31a	23.83 ± 1.19a	32.22 ± 0.54b	0.036
Shape Index	75.99 ± 0.54	75.42 ± 0.49	74.56 ± 0.55	75.19 ± 0.58	74.65 ± 2.29	0.423
Shell thickness	0.16 ± 0.29	0.15 ± 0.20	0.17 ± 0.25	0.14 ± 0.19	0.17 ± 0.25	0.743
Eggshell ratio (%)	10.01 ± 0.30	10.19 ± 0.43	10.00 ± 0.36	10.53 ± 0.29	11.27 ± 0.35	0.417
Albumen%	55.95 ± 0.83	54.34 ± 0.88a	55.87 ± 1.07	57.46 ± 0.94b	55.47 ± 0.60	0.115

In the current study, there existed no significant difference on egg shape index, shell thickness, yolk albumen ratio, eggshell ratio, and yolk ratio. However, the Haugh Unit was lower in eggs from hens on 0% BSFL, but there were no significant differences ($p>0.05$) between eggs from hens in all other diets. Previous studies by (Mwaniki *et al.*,2018) and (Al-Qazzaz*et al.*, 2016) reported an increase in shell thickness with the inclusion of BSFL but no significant differences in Haugh Unit for eggs from hens offered diets containing BSFL. This implies that BSFL had no significant influence on the egg protein quality.

The yolk ratio varied from 23.33 on the control diet to 32.22 on eggs from hens fed diet with 100% inclusion of BSFL meal**.** The yellow yolk colour intensity was different across all the diets; a Diet with 100%BSFL had the deepest yellow colour intensity at 15 according to the Roche colour scale. These results indicated that egg yolk colour intensified with increasing dietary BSFL which is similar to reports by Mwaniki *et.al* (2018) who concluded that feeding BSFL Meal significantly increased yolk colour. However, Ruhnke *et. al.* (2018), reported that egg yolk colour was considerably lighter in hens offered diets with 15.5 ± 1.7 grams BSFL/ hen/ day. This was lower compared to the current study whose minimal inclusion of BSFL was 25% per kg. Dietary energy content in BSFL Complimented the yolk colour, this is because Xanthophyll, the chief pigment that provides the egg yolk color, is fat soluble. Higher dietary fat content, for instance, enhances pigment absorption (Champrix, n.d.)

4.4 Cost-benefit analysis and return on investment

A financial comparison of replacing Soy and Fish Meal with BSFLM in the diets of indigenous chicken was evaluated using the CBR and ROI as presented on Table 4.6 below.

Table 4.4 Economic analyses of improved Kenyan Indigenous chicken fed with diets containing BSF larvae meal.

Parameters measured	0% BSFLM	25% BSFLM	50% BSFLM	75% BSFLM	100% BSFLM	p-value
Cost of feed (US$/kg)	0.42	0.45	0.43	0.43	0.44	
ADFI (g/day)	105.76 ± 13.30[a]	114.51 ± 17.74b	106.83 ± 12.38a	104.78 ± 6.38a	112.00 ± 10.98b	0.035
Total feed intake (g)	16288.00 ± 2048.91a	17634.00 ± 2731.74b	16451.00 ± 1907.18a	16136.00 ± 982.99a	17248.00 ± 1691.25b	0.001
Cost of feed consumed	0.04 ± 0.01	0.05 ± 0.01	0.04 ± 0.01	0.04 ± 0.00	0.05 ± 0.00	0.235
Total feed cost (Cf)	6.84 ± 0.86a	7.94 ± 1.23b	7.07 ± 0.82ab	6.94 ± 0.42a	7.59 ± 0.7b	0.047
Egg lay (%)	51.23 ± 12.26a	71.68 ± 24.93b	79.43 ± 14.70bc	74.54 ± 8.17b	84.10 ± 6.00c	0.001
Total eggs laid	78.90 ± 18.88a	110.39 ± 38.38b	122.33 ± 22.63c	114.80 ± 12.58b	129.52 ± 9.25c	0.001
Sale of eggs (S)	11.84 ± 2.83a	16.56 ± 5.76b	18.34 ± 3.40b	17.22 ± 1.89b	19.43 ± 1.39b	0.017
[a] Gross profit margin (Pr)	4.99 ± 2.82a	8.62 ± 5.01b	11.27 ± 2.74b	10.28 ± 1.85b	11.84 ± 1.56b	0.001
[b] Cost-Benefit Ratio	1.75 ± 0.44a	2.05 ± 0.69b	2.58 ± 0.30b	2.49 ± 0.28b	2.58 ± 0.31b	0.043
[c] Return on Investment.	74.50 ± 44.48a	105.38 ± 68.85b	158.17 ± 30.07c	148.67 ± 28.00c	158.30 ± 30.95c	0.001

Means in the same row followed by different lowercase are significantly different ($p<0.05$).1 US dollar was exchanged for 100 Kenyan shillings during the study's period Soybean meal =0.90 US$/kg, Fish meal =1.20 US$/kg, BSFLM (Black Soldier Fly Larvae meal) = 0.85 US$/kg. The cost of egg used in this analysis = 0.15 US$/Egg; [b]Pr = S – Cf; [c]CBR = S/Cf; [d]RoI = Pr/Cf*100.

This study, the expectation was that the expenditure related to the feed materials used and the subsequent revenue generated from the sale of eggs post-experiment would constitute the sole financial elements. The overall feed cost exhibited variation across the distinct treatments, with the diet incorporating 25% Black Soldier Fly Larvae (BSFL) (D1) registering the highest feed cost, whereas the control group recorded the lowest feed cost. Nevertheless, the Pr, CBR and ROI were observed to be at their lowest for the control diet. Conversely, diets incorporating 50% and 100% BSFL demonstrated the highest CBR and ROI, exhibiting similarity in their financial performance.

The study observed that as the substitution of fish and soybean meal with BSFLM increased, the total feed cost also increased. However, there was a concurrent increase in CBR and ROI. The control diet was characterized by the lowest feed cost, and also exhibited the lowest CBR and ROI. This outcome was attributed to the elevated egg production in chicken-fed diets with BSFL meal, aligning with findings from prior research by Onsongo *et al*. (2018). The latter study reported reduced feed consumption costs by increasing the substitution of fishmeal and soybean meal with BSFL in broiler diets. The heightened egg production in diets based on BSFL contributed to the enhanced CBR and ROI.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusions

- Chicken fed on diets with BSFL exhibited significantly higher: egg production (%), egg weight, and egg nutritional value.
- The inclusion of 100% BSFL meal did not have a significant difference compared to inclusion at 25% and 50% BSFL.
- BSFL meal displayed a high protein content of 43.9%, comparable to common protein sources like soybeans and fishmeal used in chicken diets.
- The return on investment was highest in diets with BSFL, particularly with 50% and 100% BSF inclusions.

5.2 Recommendations

1. 1 Optimal Inclusion Level: The study recommends including BSFL at 50% and 100% in chicken diets
2. Protein Source Diversity: Recommends promoting the use of BSFL as a protein source to diversify and enhance the nutritional profile of chicken diets.
3. Economic Viability: It is recommended to consider the cost-effectiveness of BSFL inclusion in feed formulations.
4. Further Research and Monitoring: it is recommended to conduct further research to explore any potential benefits or challenges associated with higher inclusion levels of BSFL. Continuous monitoring and evaluation will help in refining recommendations and understanding the long-term effects on chicken performance and egg quality.

REFERENCES

Albertaaquaponics (2019). Black soldier fly larvae now on stock. http://www.albertaaquaponics.ca/tag/black-soldier-fly-larva. (Accessed: 22nd January, 2019)

Al-Qazzaz1, M.F.A., Ismail Dahlan, Akit Henny. Idris Lokman Hakim (2016). Effect of using insect larvae meal as a complete protein source on quality and productivity characteristics of laying hens. Revista Brasileira de Zootecnia, 45(9), 518-523. Available on: http://dx.doi.org/10.1590/s1806-92902016000900003.

Association of Official Analytical Chemists. (1990). Official methods of analysis of the AOAC (15th ed.). Methods 932.06, 925.09, 985.29, 923.03.

Bovšková, H., Míková, K., & Panovská, Z. (2014). Evaluation of egg yolk colour. Czech Journal of Food Science, 32(3), 213–217.

Champrix. (n.d.). Importance of proteins in the daily diet of poultry. Retrieved from https://champrix.com/articles/importance-of-proteins-in-the-daily-diet-of-poultry

Charlton, A. J., Dickinson, M., Wakefield, M. E., Fitches, E., Kenis, M., Han, R., Zhu, F., Kone, N., Grant, M., Devic, E., Bruggeman, G., Prior, R., & Smith, R., (2015). Exploring the chemical safety of fly larvae as a source of protein for animal feed. Journal of Insects as Food and Feed: 1, 7-16. Available on: https://doi.org/10.3920/JIFF2014.0020

De-pach, Y. M., (2012). Effect of feed enzymes and energy level on broiler chicken (Gallus domesticus) Performance in Kenya. M.Sc (Agric) thesis. University Nairobi, Nairobi, Kenya.

Dikmen, Bilgehan Yilmaz; Ipek, Aydin; Şahan, Ümran; Sözcü, Arda; And Baycan, Süleyman Can (2017). Impact of different housing systems and age of layers on egg quality characteristics. Turkish Journal of Veterinary & Animal Sciences, 41(1). https://doi.org/10.3906/vet-1604-71

DSM Animal Nutrition and Health (n.d)., DSM egg yolk pigmentation guidelines. Retrieved from https://www.dsm.com/anh/en/feedtalks/eggyolk-pigmentation-guidelines.html

Ege, G., Bozkurt, M., Koçer, B., Tüzün, A. E., Uygun, M., & Alkan, G. (2019). Influence of feed particle size and feed form on productive performance, egg quality, gastrointestinal tract traits, digestive enzymes, intestinal morphology, and nutrient digestibility of laying hens reared in enriched cages. Poultry Science, 98(9), 3787-3801. https://doi.org/10.3382/ps/pez082

Food and Agriculture Organization of the United Nations. (2003). Egg marketing: A guide for the production and sale of eggs (FAO) Agricultural Services Bulletin No. 150). Rome. Retrieved from https://www.fao.org/3/Y4628E/y4628e00.htm#Contents

(FAO,2012). The role of livestock in developing countries. In FAO (Ed.), Livestock in a changing landscape, Volume 1: Drivers, consequences, and responses. FAO. Retrieved from https://www.fao.org/3/i2490e/i2490e00.htm

Food and Agriculture Organization of the United Nations. (2013).

Livestock Sector Brief: Asia and the Pacific Region (ISBN 978-92-5-108067-2). Retrieved from https://www.fao.org/3/i3531e/i3531e.pdf.

Food and Agriculture Organization of the United Nations. (2014). Food and nutrition in numbers [Brochure]. FAO. Retrieved from https://www.fao.org/3/i4175e/i4175e.pdf.

FAO (2019), Aquaculture Feed and Fertilizer Resources Information System, Food and Agriculture Organization of the United Nations http://www.fao.org/fishery/affris/feed-and-feed-ingredient-standards/viet-nam-feed-and-feed-ingredient-standards/en. Date accessed: 17th, February, 2019

Farrell, D. J., (1974). A new, Rapid Method for Determining the Metabolizable Energy of Poultry Feedstuffs. Department of Biochemistry and Nutrition, University of New England. Armadale, N.S.W. 2351

Food and Agriculture Organization of the United Nations. (2003). Egg marketing: A guide for the production and sale of eggs (FAO Agricultural Services Bulletin No. 150). Rome.

Gerzilov, V., Datkova, V., Mihaylova, S., & Bozakova, N. (2011). Effect Of Poultry Housing Systems On Production of Eggs. Bulgarian Journal of Agricultural Science, 18(6), 953-957

HEDEGAARD foods (n.d), Structure of an egg. http://en.eggs.dk/the-egg/structure-of-the-egg.aspx Date accessed: 22nd January, 2019

International Livestock Research Institute. (n.d.). Kenyan livestock sector to grow exponentially. ILRI. Retrieved from https://www.ilri.org/news/kenyan-livestock-sector-grow-exponentially-kenya-national-bureau-statistics

He, W., Li, P., Wu, G. (2021). Amino Acid Nutrition and Metabolism in Chickens. In: Wu, G. (eds) Amino Acids in Nutrition and Health. Advances in Experimental Medicine and Biology, vol 1285. Springer, Cham. https://doi.org/10.1007/978-3-030-54462-1_7

Jacob, J., Wilson, H. R., Miles, R. D., Butcher, G. D., & Mather, F. B. (2014). Factors affecting egg production in backyard chickens. University of Florida, 1-8.

KALRO (Kenya Agricultural and Livestock Research Organization). (n.d.). Official Website. Retrieved from https://www.kalro.org/

KARI (2014). KARI Kuku Kienyenji retrieved from https://www.youtube.com/watch?v=2WcrBzJQzco&t=8s (Date accessed: 18th July 2018)

Kenya Agribusiness and Agroindustry Alliance. (n.d.). Indigenous chicken give better returns. Retrieved from https://kaaa.co.ke/indigenous-chicken-give-better-returns/#:~:text=An%20exotic%20breed%20such%20as,250%20eggs%20under%20good%20management.

Kingori A.M, Tuitoek J.K, Muiruri H.K., and Wachira A.M. (2003) Protein requirements of growing indigenous chickens during the 14-21 weeks growing period. South African Journal of Animal Science 2003, 33(2): 78-82 DOI:10.4314/sajas.v33i2.3759

Kristl, M., Jurak, S., Brus, M., Sem, V., & Kristl, J. (2019). Evaluation of calcium carbonate in eggshells using thermal analysis. Journal of Thermal Analysis and Calorimetry, 138, 2751-2758.

Latshaw, L. D., & Freeland. (2008). Metabolizable Energy Values Determined with Intact and Cecectomized Roosters, Poultry Science 87: 101–103 doi:10.3382/ps.2007-00127

Lee, Min, Jung, Cho, Choi, Eun, Bang, Min, Sohn, Sea. (2016). The Effect of Hen Age on Egg Quality in Commercial Layer. Korean Journal of Poultry Science. 43, 253-261. 10.5536/KJPS.2016.43.4.253

Lemlem A and Tesfay Y 2010: Performance of exotic and indigenous poultry breeds managed by smallholder farmers in northern Ethiopia. *Livestock Research for Rural Development. Volume 22, Article #133.* Retrieved February 15, 2024, from http://www.lrrd.org/lrrd22/7/leml22133.htm

Liu, Xiu., Chen, Xuan., Wang, Hui., Yang, Qinqin., Rehman, Kashif., Li, Wu., Cai, Minmin., Li, Qing., Mazza, Lorenzo., Zhang, Jibin., Ziniu, yu., Zheng, Longyu., (2017). Dynamic changes of nutrient composition throughout the entire life cycle of black soldier fly. PLOS ONE. 12(8). DOI: 10.1371/journal.pone.0182601

Lordelo, M., Fernandes, E., Bessa, R. J. B., & Alves, S. P. (2017). Quality of eggs from different laying hen production systems, from indigenous breeds and specialty eggs. Poultry Science, 96(5), 1485-1491.

Maglangit, F., Alosbanos, R.S., & Akeed, M. (2021, February 25). Black Soldier Fly. In Encyclopedia. Retrieved from https://encyclopedia.pub/entry/7597

Makkar, H. P. S., Tran, G., Heuze, V., Ankers, P. (2014). State-of-the-art on use of insects as animal feed. Animal Feed Science and Technology 197: 1–33

Ministry of Agriculture, Livestock and Fisheries. (2019). Annual report.

Moreki J. C, Tiroesele B. and Chiripasi S. (2012) Prospects of Utilizing Insects as Alternative Sources of Protein in Poultry Diets in Botswana: a Review. Journal of Animal Science 2012, 2(8): 649-658.

Mottet, A., & Tempio, G. (2017). Global poultry production: current state and future outlook and challenges. World's Poultry Science Journal, 73(2), 245–256. doi:10.1017/S0043933917000071

Mwaniki, Z., Neijat, M., & Kiarie, E. (2018). Egg production and quality responses of adding up to 7.5% defatted black soldier fly larvae meal in a corn–soybean meal diet fed to Shaver White Leghorns from wk 19 to 27 of age. Poultry Science, 97(8), 2829-2835.

Mwaniki, Z. (2019). Complete replacement of soybean meal with defatted black soldier fly larva meal (BSFLM) in laying hen feeding programs: impact on egg production and quality (Doctoral dissertation, University of Guelph).

National Research Council (NRC). (1994). Nutrient requirements of poultry. 9th Revised Edition, National Academy Press, Washington, DC.

Newton G. L., Booram, C. V. Barker R. W. & O. M. Hale. J. (1977) Dried Hermetia Illucens Larvae Meal as a Supplement for Swine Journal of Animal Science, 44: 395-400.

Perić, L., Đukić Stojčić, M., & Bjedov, S. (2017). The Effect of Storage and Age of Hens on the Quality of Table Eggs. Advanced Research in Life Sciences, 1(1), 64-67. https://doi.org/10.1515/arls-2017-0011

Roberts, J.R., Chousalkar, Kapil., Samiullah (2013.) Egg quality and age of laying hens: Implications for product safety, Animal Production Science, 53, 1291–1297

Ruhnke, I., Normant, C., Campbell, D. L., Iqbal, Z., Lee, C., Hinch, G. N., & Roberts, J. (2018). Impact of on-range choice feeding with black soldier fly larvae (Hermetia illucens) on flock performance, egg quality, and range use of free-range laying hens. Animal nutrition, 4(4), 452-460.

Samiullah, S., Saleh Omar, A., Roberts, J., & Chousalkar, K. (2017). Effect of production system and flock age on eggshell and egg internal quality measurements. Poultry Science, 96(1), 246-258. https://doi.org/10.3382/ps/pew289

Shcherbatov, V. I., & Shkuro, A. G. (2021). Cycles and Intervals in Hen Egg Laying. E3S Web of Conferences, 335, 00013. https://doi.org/10.1051/e3sconf/202133500013

Sher-e-Bangla Agricultural University. (n.d.). Retrieved from https://sau.edu.bd/uploads/pdf/dept/class_lecture/24_2020-08-11_5f32fee3c41d6.pdf

Sharma, M. K., McDaniel, C. D., Kiess, A. S., Loar, R. E. II, & Adhikari, P. (2022, February). Effect of housing environment and hen strain on egg production and egg quality as well as cloacal and eggshell microbiology in laying hens. Poultry Science, 101(2), 101595. https://doi.org/10.1016/j.psj.2021.101595

Shrivastava, M., Kumar, S., Kumar, R., & Mallick, P. K. (2022). Egg production, feed efficiency, economics and microbial quality of eggs under different rearing systems. Poultry Science, 101(1), 101442. https://doi.org/10.1016/j.psj.2021.101442

Shrivastava, M., Kumar, S., Kumar, R., Mallick, P. K., & Bhatt, R. S. (2021). Egg quality traits of native chickens in different production systems. Poultry Science, 100(3), 101098. https://doi.org/10.1016/j.psj.2020.12.012

Sinclair-Black, M., Garcia, R. A., & Ellestad, L. E. (2023). Physiological regulation of calcium and phosphorus utilization in laying hens. Frontiers in Physiology, 14, 1112499.

Skřivan, M., Englmaierova, M., Marounek, M., Skřivanová, V., Taubner, T., & Vit, T. (2016). Effect of dietary magnesium, calcium, phosphorus, and limestone grain size on productive performance and eggshell quality of hens.

Spranghers, T., Ottoboni, M., Klootwijk, C., Ovyn, A., Deboosere, S., De.Meulenaer, B., Michiels, J., Eeckhout, M., De Clercq, P., & De Smet, S. (2017). Nutritional composition of black soldier fly (Hermetia illucens) prepupae reared on different organic waste substrates. J. Sci. Food Agric. 97: 2594–2600.

Sultan, A., Obaid, H., Khan, S., Rehman, I. U., Shah, M. K., & Khan, R. U. (2015). Nutritional effect of flaxseeds on cholesterol profile and fatty acid composition in egg yolk. Cereal Chemistry, 92(1), 50-53.

Talukder, S., Islam, T., Sarker, S., & Islam, M. M., (2010) Effects of environment on layer performance. J. Bangladesh Agril. University. 8(2): 253–258

Thirumalaisamy, G., Muralidharan, J., Senthilkumar, S., Hema Sayee, R., & Priyadharsini, M. (2016). Cost-effective feeding of poultry. International Journal of Science, Environment and Technology, 5(6), 3997-4005.

University of Florida. (n.d.). Poultry Nutrition: Feeding Broiler Breeders. EDIS - Electronic Data Information Source of UF/IFAS Extension. Retrieved from https://edis.ifas.ufl.edu/publication/IN830

Van Huis, Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., Vantomme, P., FAO (2013) Forestry paper 171 Edible Insects: Future prospects for food and feed security

Virginia Cooperative Extension. (n.d.). Poultry: Anatomy of an egg. Retrieved from https://www.sites.ext.vt.edu/virtualfarm/poultry/poultry_eggparts.html

Wallace, S. M., & Guillaume, T. (2019). Scoping assessment of potential beneficial use of insect frass as a soil amendment. Waste Management & Research, 37(4), 357-364.

Watanabe, S. (2002). Proteolytic enzymes from an Aspergillus species hydrolyzing the vitellin of hen egg yolk. Animal Science Journal, 73(5), 431-440.

APPENDICES

Appendix I: Research Approval from Graduate School

KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 020-8704150

Internal Memo

FROM: Dean, Graduate School

DATE: 28th February, 2017

TO: Damaris Wacu Nyingi
C/o Agricultural Resource
Management Department.

REF: A146/OL/NKU/24500/2014

SUBJECT: APPROVAL OF RESEARCH PROPOSAL

This is to inform you that Graduate School Board, at its meeting of 8th February, 2017, approved your Research Proposal for the M.Sc. Degree entitled **"Insect Feed Utilization in Layer Diets: Effects on Performance and Egg Quality in Improved Indigenous Chicken"**.

You may now proceed with your Data collection, subject to clearance with the Director General, National Commission for Science, Technology and Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking Forms per semester. The form has been developed to replace the Progress Report Forms. The Supervision Tracking Forms are available at the University's Website under Graduate School webpage downloads.

Thank you.

GIDEON KAIMENYI
FOR: DEAN, GRADUATE SCHOOL

CC. Chairman, Agricultural Resource Management Department

GK/rwm

Appendix II: Research Authorization from Graduate School

KENYATTA UNIVERSITY
OFFICE OF THE DEAN, GRADUATE SCHOOL

E-mail: dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 020-8704150

Our Ref: A146/OL/NKU/24500/2014

DATE: 28th February 2017

Director General,
National Commission for Science, Technology and Innovation
P.O. Box 30623-00100
NAIROBI

Dear Sir/Madam,

RE: RESEARCH AUTHORIZATION FOR MS. DAMARIS WACU NYINGI REG.NO. A146/OL/NKU/24500/2014

I write to introduce Ms. Damaris Wacu Nyingi who is a Postgraduate Student of this University. She is registered for M.Sc. degree programme in the **Department of Agricultural Resource Management.**

Ms. Damaris Wacu Nyingi intends to conduct research for a M.Sc. Thesis Proposal entitled, ***"Insect Feed Utilization in Layer Diets: Effects on Performance and Egg Quality in Improved Indigenous Chicken".***

Any assistance given will be highly appreciated.

Yours faithfully,

PROF. PAUL OKEMO
DEAN, GRADUATE SCHOOL

Appendix III: Research Permit from NACOSTI

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **161860**

Date of Issue: **04/March/2024**

RESEARCH LICENSE

This is to Certify that Ms.. Damaris Wacu Nyingi of Kenyatta University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nakuru on the topic: Insects feed utilization in layer Diets:effects on performance and Egg Quality in Improved Indigenous Chicken for the period ending : 04/March/2025.

License No: **NACOSTI/P/24/33395**

161860

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions

THE SCIENCE, TECHNOLOGY AND INNOVATION ACT, 2013 (Rev. 2014)

Legal Notice No. 108: The Science, Technology and Innovation (Research Licensing) Regulations, 2014

The National Commission for Science, Technology and Innovation, hereafter referred to as the Commission, was the established under the Science, Technology and Innovation Act 2013 (Revised 2014) herein after referred to as the Act. The objective of the Commission shall be to regulate and assure quality in the science, technology and innovation sector and advise the Government in matters related thereto.

CONDITIONS OF THE RESEARCH LICENSE

1. The License is granted subject to provisions of the Constitution of Kenya, the Science, Technology and Innovation Act, and other relevant laws, policies and regulations. Accordingly, the licensee shall adhere to such procedures, standards, code of ethics and guidelines as may be prescribed by regulations made under the Act, or prescribed by provisions of International treaties of which Kenya is a signatory to
2. The research and its related activities as well as outcomes shall be beneficial to the country and shall not in any way;
    i. Endanger national security
    ii. Adversely affect the lives of Kenyans
    iii. Be in contravention of Kenya's international obligations including Biological Weapons Convention (BWC), Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), Chemical, Biological, Radiological and Nuclear (CBRN).
    iv. Result in exploitation of intellectual property rights of communities in Kenya
    v. Adversely affect the environment
    vi. Adversely affect the rights of communities
    vii. Endanger public safety and national cohesion
    viii. Plagiarize someone else's work
3. The License is valid for the proposed research, location and specified period.
4. The license any rights thereunder are non-transferable
5. The Commission reserves the right to cancel the research at any time during the research period if in the opinion of the Commission the research is not implemented in conformity with the provisions of the Act or any other written law.
6. The Licensee shall inform the relevant County Director of Education, County Commissioner and County Governor before commencement of the research.
7. Excavation, filming, movement, and collection of specimens are subject to further necessary clearance from relevant Government Agencies.
8. The License does not give authority to transfer research materials.
9. The Commission may monitor and evaluate the licensed research project for the purpose of assessing and evaluating compliance with the conditions of the License.
10. The Licensee shall submit one hard copy, and upload a soft copy of their final report (thesis) onto a platform designated by the Commission within one year of completion of the research.
11. The Commission reserves the right to modify the conditions of the License including cancellation without prior notice.
12. Research, findings and information regarding research systems shall be stored or disseminated, utilized or applied in such a manner as may be prescribed by the Commission from time to time.
13. The Licensee shall disclose to the Commission, the relevant Institutional Scientific and Ethical Review Committee, and the relevant national agencies any inventions and discoveries that are of National strategic importance.
14. The Commission shall have powers to acquire from any person the right in, or to, any scientific innovation, invention or patent of strategic importance to the country.
15. Relevant Institutional Scientific and Ethical Review Committee shall monitor and evaluate the research periodically, and make a report of its findings to the Commission for necessary action.

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