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PARTIAL SOYBEAN CAKE REPLACEMENT WITH BLACK SOLDIER FLY LARVAE: EFFECTS ON PERFORMANCES, CARCASS TRAITS, BREAST MEAT ATTRIBUTES AND ECONOMIC EFFICIENCY IN BROILERS

MSC THESIS

BY:

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MSC Program in Poultry Health and Management

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Bishoftu, Ethiopia

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A Thesis submitted to the College of Veterinary Medicine and Agriculture of Addis Ababa University in partial fulfillment of the requirements for the degree of Masters of Science in Poultry Health and Management

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Partial Soybean Cake Replacement with Black Soldier Fly Larvae: Effects on Performances, Carcass Traits, Breast Meat Attributes and Economic Efficiency in Broilers

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LIST OF ABBREVIATIONS AND ACRONYMS

ADG	Average Daily Gain
AAU	Addis Ababa University
AME	Apparent Metabolisable Energy
BC	Broiler Concentrate
BSFL	Black Soldier Larvae
BSFLM	Black Soldier Fly Larvae Meal
BW	Body Weight
ADFI	AVERAGE Daily Feed Intake
BWG	Body Weight Gain
CA	Crude Ash
CF	Crude Fiber
CNCS	College of Natural and Computational Science
CP	Crude protein
CSA	Central Statistics Authority
CVMA	College of Veterinary Medicine and Agriculture
DFI	Daily Feed Intake
DM	Dry Matter
DOC	Day Old Chicks
EE	Ether Extract
EIAR	Ethiopian Institute of Agricultural Research
FCR	Feed Conversion Ratio
FI	Feed Intake
GIT	Gastro Intestinal Tract
HI	*Hermetia illucens*
LW	Live Weight
MBM	Meat Bone Meal
NIRS	Near Infrared Spectroscopy
NVI	National Veterinary Institute
SBC	Soybean cake

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

SEM	standard error of the mean
SO	Soybean Oil
VPH	Veterinary Public Health
WB	wheat bran
WM	wheat middling

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ABSTRACT

By 2050, there will be about 9.7 billion people on the planet, which needs sustainable, efficient and alternative sources of proteins to feed animals that used for human consumption. This study evaluated the effects of replacing soybean cake (SBC) in broiler chicken diets with black soldier fly larvae meal (BSFLM) in terms of growth performance, carcass characteristics, meat quality and economic efficiency. A total of 156 Cobb-500 broiler day old chicks were assigned to four treatments: control (TR0), 15% (TR1), 30% (TR2), and 45% (TR3) BSFLM replacement levels for SBC. Over a 42-day feeding period, TR1 (15% substitution) produced the highest final body weight (2,077.6 g) and average daily gain (49.5 g/day), significantly outperforming TR3 (1,900.9 g; 45.9 g/day) ($p < 0.05$). Feed conversion ratios remained optimal at 1.65 in TR1, while higher substitution levels (TR2 and TR3) resulted in performance decline. Carcass yield reflected growth trends, with TR1 showing superior live weight at slaughter (2,315 g) and dressed weight (1,767 g), and the highest dressing percentage (76.3%), compared to TR3 (1,964 ; 1,460 g; 74.5%) ($p < 0.05$) but it has not shown any significant differences from TR0 and TR2. Meat quality analyses revealed no significant differences in crude protein content (~23.7%), but a marked reduction in crude fat was observed in TR1 (6.3%) compared to TR0 (8.0%) ($p = 0.044$). Drip loss (3.5–4.0%), cook loss (23.4–28.6%), and textural properties (hardness, springiness, cohesiveness) were consistent across treatments, although higher BSFLM levels resulted in minor alterations in meat colors, lightness (L) increased (up to 46.0 in TR3), redness (a*) decreased (2.5 in TR1/TR2 vs. 3.1 in TR0), and yellowness (b*) increased at higher inclusion levels. Economic analysis demonstrated that TR1 achieved the lowest feed cost per kg of carcass weight (109.4 birr), compared to 111.7 birr in TR0, while TR2 and TR3 incurred higher costs due to reduced growth performance and carcass yield. According to these results, a moderate replacement of SBC with BSFLM (15%) promotes the sustainable integration of insect-based proteins into broiler chicken production systems while optimizing broiler growth, carcass traits, and financial returns without compromising meat quality. Further studies are recommended to refine inclusion levels, cost-effectiveness, and environmental impacts.*

Key words: *Black Soldier Fly, Broiler, Carcass, Economy, Larvae Meal, Performance, Soybean cake*

1. INTRODUCTION

1.1. Background

As the world's population is predicted to grow by 8.5 billion people by 2030 and 9.7 billion by 2050 (UN, 2019), and as urbanization increases, it is imperative to create and supply safe, sustainable food systems in general and animal-based food sources in particular (FAO, 2014). As the population grows by 83 million per year, food production must increase by 70% to keep up with demand, which will intensify competition for arable land and natural resources like water and energy (FAO, 2020). Because of its high feed conversion efficiency and quick growth rate, broiler chicken production is one of the most cost-effective and straightforward ways to close the animal protein supply-demand imbalance (Onu *et al.*, 2011).To achieve the critical amino acid requirements for growth and carcass production, broiler farming necessitates higher protein intakes. To date, the primary protein sources for poultry consumption and carcass production have been soybeans (Hossain and Blair, 2007; Lázaro *et al.*, 2006).

Producers and consumers of poultry products appear to be open to using insects to feed their poultry and are willing to consume products collected from insect fed animals (Verbeke *et al*., 2015). According to Makkar *et al.* (2014), they may possess an essential amino acid profile that corresponds with the necessary amino acid profiles of broiler chickens and growing pigs. By allowing insects to feed on organic waste, Gariglio *et al.* (2019) claimed that adding insect products to poultry diets could lessen the negative environmental effects of poultry production by reducing the quantity of organic waste that ends up in landfills and other waste disposal locations. For broiler chickens, insect fat is often regarded as a unique energy source (Kieronczyk *et al.*, 2020).Although many insects are being tested as alternatives to conventional poultry feed, the larvae of the black soldier fly (*Hermetia illucens*; HI) are perhaps one of the most promising insect species. This is due to its essential nutritional value and the possibility of using a variety of farming substrates (Meneguz *et al.*, 2018). Additionally, unlike many pests that eat waste, black soldier fly larvae are able to inactivate *Salmonella specie s*and *Escherichia coli* (Erickson *et al.*, 2004).

Due to their higher lipid content (7–39% DM) and protein content (37–63% DM), which has a more advantageous amino acid profile than soybean cake (SBC), black soldier fly larvae are gaining attentions to use them as animal feed (Barragan-Fonseca *et al.*, 2017). The birds' growth performance, nutritional digestibility, and physiological reactions were comparable when fed dietary fat extracts derived from BSFL. Additionally, the gastrointestinal tract (GIT) microbial communities and immunological condition are positively impacted by the high content of lauric acid in the larvae (C12:0) (Kieronczyk *et al.*, 2022).According to earlier research, using BSF larvae fat either by itself or in conjunction with soybean oil did not impair the growth performance of laying hens (Kim *et al.*, 2022), turkeys (Kierończyk *et al.*, 2022b), or broiler chickens (Schiavone *et al.*, 2016).

In addition to being relatively rich in lysine and methionine, the black soldiers fly larvae meal (BSFLM) is high in nitrogen (N) (up to around 100 g/kg dry matter (DM)) (Heuel*et al.*, 2021). Additionally, untreated BSFL are high in calcium, phosphorus, and energy (up to 400 g ether extract/kg DM) (Barragan-Fonseca *et al.*, 2017). Broilers fed BSFL instead of some (10–20%) soybean cake in the diet showed similar production performance, feed efficiency, mortality, and carcass characteristics to those fed commercial diets (Arango Gutiérrez, 2005; Cullere *et al.*, 2016; Zhang *et al.*, 2014). Despite these nutritional benefits, more research is needed to determine the best level of substitution in the diets of broilers for protein and fat sources, the negative effects on health, meat quality, carcass yield and traits, broiler performance metrics and the economic feasibility of the replacement plans.

1.2. Problem Statement

Despite black soldier fly larvae (BSFL) being rich in protein, essential amino acids (lysine, methionine), lipids, and minerals, there is insufficient research on their capacity to fully or partially replace conventional protein sources like soybean meal in broiler diets without compromising growth performance or meat quality. Due to this there is a lack of comprehensive data determining the optimal levels of BSFL meal and fat substitution in broiler diets to maximize nutrient digestibility, immune function, and gut health, while minimizing potential adverse effects (Barragán-Fonseca *et al*., 2017). Additionally the economic feasibility of incorporating BSFL meal and fat into broiler diets remains uncertain due to limited data on production costs, market pricing, and cost-benefit comparisons with conventional feed ingredients (Van Huis *et al*., 2017).

1.3. Objectives

1.3.1. General objective

- To determine the effects of partial substitution of the soybean cake portion of broiler diet with BSFL meal in broiler chicken diets on growth performance, carcass characteristics, physical and chemical meat quality, economic efficiency.

1.3.2. Specific objectives

- To identify the best substitution level BSFLM with soybean cake
- To assess carcass traits and meat quality of broiler chicken fed diets containing BSFLM
- Analyze the economic the economic benefit of partially replacing soybean cake with BSFLM

2. LITERATURE REVIEW

2.1. Life Cycle and Production of Black Soldier Fly

Recent research suggests that adding insect meals to feed formulation may improve the sustainability of the chicken supply chain because insects are a natural component of poultry feed (Abd El-Hack *et al.*, 2020). Numerous *Dipteran and Coleopteran* species can be raised on low-grade biological waste and produced into high-quality proteins. In chicken diets, BSFL seems to have a lot of potential to replace soybeans (Heuel *et al.*, 2022). In order to meet the demands of livestock production in the future, black soldier fly larvae are showing promise as an alternative feed source. Studies have shown that including BSFL in broiler chicken diets by replacing soybean portion of the feed partially can enhance productivity, welfare, and product quality (Gadzama *et al.*, 2025).

Although it can be found all over the world, the equatorial tropics are where the black soldier fly is most common (Brammer and vonDohlen, 2007). According to UrRehman *et al.* (2017), they consume a lot of organic wastes, including rotting fruits, animal manure, vegetable trash, and municipal organic waste. The BSF life cycle consists of four stages: the egg, larva, pupa, and adult (Tomberlin and Sheppard, 2002). During the special last stage of the larval stage, the prepupae move to a suitable and dry pupation place and change into pupae (Diener *et al.*, 2011).

Adult flies are not pests or disease-carrying insects. Having previously accumulated fat during their larval stage, they now only need water to survive (Paulk and Gilbert, 2006). The female BSF merely deposits their eggs around the edges of the larval feeding source rather than on the feed itself. As a result, infections are not transmitted by the wastes (Booth and Sheppard, 1984). According to Makkar *et al.* (2014), this insect can reduce pollution from plant and animal wastes by up to 50% in addition to reducing the amount of houseflies and harmful pathogens.

Human waste (Van Huis *et al.*, 2013; Nguyen *et al.*, 2013), vegetable waste (Parra Paz *et al.*, 2015), human food waste (Banks *et al.*, 2014), swine manure, poultry manure, and dairy manure (Zhou *et al.*, 2013) are all converted by BSFL to recycle wasted nutrients. Manures and wastes provide about 30% of BSF's fat and 40% of its protein (Makkar *et al.*, 2014). Lipid accumulation varies depending on the larvae's dietary materials (substrates) (Li *et al.*, 2015). Black soldiers fly is widely used as a premium feed source in the livestock and aquaculture feed industries (Makkar *et al.*, 2014; Schiavone *et al.*, 2017a). Waste-to-Energy technology is more practical since bio-fuel may be made from BSFL, a special biological raw material (Zheng *et al.*, 2012).

In order to produce black soldier fly larvae (BSFL), *Hermetia illucens* must be raised in controlled settings with sufficient humidity (60–70%), temperature (27–30°C), and light. Organic waste, such as food scraps, manure, or agro-industrial byproducts, is used as feed. With a dry larval output of 15–25% and a bioconversion efficiency of up to 20%, depending on substrate quality and rearing conditions, the larvae are extremely effective bio-converters that may convert organic waste into valuable biomass (van Huis, 2020). In order to create high-protein meal (40–65% crude protein) and lipid-rich oil that are both appropriate for animal feed applications because of their high digestibility and amino acid content, BSFL are normally processed after harvesting by drying (in the sun, oven, or microwave), grinding, and occasionally defatting (Makkar *et al*., 2014). Systems differ in terms of productivity and output per unit waste, but research shows that one ton of food waste can produce 80–120 kg of dried larvae, highlighting the potential of BSFL to support sustainable livestock production systems and the circular bioeconomy (Gold *et al*., 2018).

2.2. Importance of Black Soldier Fly Larvae as Animal Feed Replacement

Increasing the development of alternative protein sources is one way to decrease the amount of cropland used for animal feed. The main sources of protein for animal nutrition, such as fish meal, soybeans, and peas, are growing more and more expensive due to rising demand, which makes their long-term use unsustainable (de Souza-Vilela *et* *al.*, 2019). This promotes the use of non-conventional animal feed for production as a means of mitigating the effects of climate change, water scarcity, and the loss of arable land (Cutrignelli *et al.*, 2018).

In addition to their potential as an alternative feed item in various mono-gastric animal diets, such as those for dogs, pigs, fish, and poultry, black soldier fly larvae (BSFL) are well-known for their ability to decrease the quantity of organic waste that is dumped in landfills (Cutrignelli *et al.*, 2018). Because their bodies contain different amounts of crude protein, crude fat, and minerals, they can also be employed to effectively decrease organic waste and create useful, nutritious larvae for animal feed (Nguyen *et al.*, 2015).

Black soldier fly larvae (BSFL) have been used in poultry feed as a partial replacement for maize or soy-based diets because the species naturally colonizes and decomposes chicken manure, and poultry farms often maintain populations of the species for waste management and pollution reduction (Bradley *et al.*, 1984; Bradley and Sheppard, 1984). According to the findings of the study by Kielończyk *et al.* (2022a), the metabolizable energy of fat from BSF larvae for broiler chickens is comparable to that of soybean oil.

2.3. Effect of Black Soldier Larvae on Broiler Chickens Performance Parameters

Male broiler chickens may benefit from higher levels of dietary BSFL meal inclusion by replacing soybean during the starter period in terms of live weight (LW) and daily feed intake (DFI), but this may also have a negative impact on the feed conversion ratio (FCR) and gut morphology. This suggests that lower levels may be more appropriate (Dabbou *et al.*, 2018). When compared to Kenyan soybean and fish meal diets, the full-fat BSFL can replace up to 15% of the conventional feed ingredients in broiler diets, lowering feed costs by 19%. This suggests that BSFL may already be a less expensive ingredient option with no negative effects on broiler production performance parameters in some countries (Onsongo *et al.*, 2018).In comparison to soybean oil diet control groups, a study conducted by Kierończyk *et al.* (2022a) found no influence on growth performance measures (BW, FI, and ADG) in turkeys when soybean oil was partially (50%) and completely substituted with BSFL meal.

Similar research on the addition of BSFL at varying amounts over the three feeding periods (starter, grower, and finisher) by de Souza Vilela *et al.* (2021) revealed that adding 2.5%–10% of the feed during the starter phase had no effect on the final BW, FI, or ADG. However, as the amount of replacement to conventional feed source rises, the final BW, ADG, and FCR are compromised and improved when BSFL is added to the feed at a rate of 5% to 20% during the grower and finisher phases. According to a study by Balolong *et al.* (2020), broilers that were fed 25%, 50%, 75%, and 100% BSFL did not exhibit any appreciable differences in the proximate composition of meat, dressing percentage, or dressing weight of broiler chicken. This study compared the effects of BSFL inclusion in varying proportions by replacing the commercial feed.

Both linear and quadratic responses were displayed by broilers fed increasing amounts of BSFLM; during all growth stages, the broilers fed up to 15% BSFLM exhibited the strongest correspondence with that of commercial diets (Dabbou *et al.*, 2018). Additionally, broilers from the insect-based feeding groups performed better than those from the control soybean cake group, and they stored more nitrogen in their bodies compared to the group that solely ate non-insect sources according to Heuel *et al.* (2022).

Kierończyk *et al.* (2020) examined broiler growth performance and found no apparent variations in BWG, FI, or FCR values. In comparison to the SO control group, pigeons fed complete BSFL fat diets showed a decrease in FI throughout the first two weeks of life. However, over the entire trial time, no appreciable changes were noticed. Nevertheless, the application of BSFL fat in broiler chicken diets significantly altered the FCR value in the first 14 days of broilers, with lower FCR is found in 75% and 100% BSFL substituted diets, but did not significantly affect the FCR value throughout the experiment. Adding 5–20% of the broiler diet to larval meal during the 5-week growth phase resulted in a significant increase in live body weight. The group fed with a 15%

larval meal diet had the highest body weight, 1.785kg vs. 1.638kg, compared to the control group (Hwangbo *et al.*, 2009).

When BSFL was added to broiler diets, average daily weight gain increased quadratically and linearly, while gain decreased linearly in the last stage (Dabbou *et al.*, 2018). Similar results were reported in previous studies, with no significant differences observed in terms of daily growth or final weight in broiler quails fed a soybean cake-based control diet or a meal containing BSFLM during the grower phase (Cullere *et al.* 2016). These favorable outcomes could be attributed to the higher nutrient content of larvae meal relative to soybean cake, particularly in essential amino acids (29.5% vs. 18.3%, respectively), as well as the better digestibility values of crude protein and amino acids in larvae relative to soybean cake (Hwangbo *et al.*, 2009).

2.4. Effect of Black Soldier Fly Larvae on Carcass Traits and Meat Quality

Black soldiers fly larvae (BSFL) supplementation has no effect on the oxidative status, cholesterol composition, or the sensory qualities and flavor perceptions of breast meat, but it does improve the amino acid composition of the meat for greater nutritional value (increased aspartic acid, glutamic acid, alanine, serine, tyrosine, and threonine). However, it increased the levels of monounsaturated and saturated fatty acids, which are undesirable (Cullere *et al.*, 2016).But, the negative impact on fatty acid profiles was mitigated when broiler chicks (*Gallus gallus domesticus*) were supplemented with defatted BSFL (Schiavone *et al.*, 2017b). Furthermore, black soldier fly larvae have a high crude protein and ether extract content, and they may substitute 33% of fish meal in broiler growers' diets without negatively affecting the birds' development, carcass yield, or health (Mohammed *et al.*, 2017).

In order to assess the impact of adding live BSFL at a rate of 5% daily feed intake (DFI), which is based on dry matter (DM), to the diets of broiler chickens, Bellezza *et al.* (2021) found that neither growth performance parameters nor carcass yield were impacted by dietary treatments. The growth or slaughter performance, pH, color, chemical composition of the breast and thigh muscles, gut morphometric indices, and histopathological changes in all the organs were unaffected by the partial substitution of soy bean oil with both modified and non-modified black soldier fly larvae fat from 3% to 17% (Dabbou *et al.*, 2021).

When more than 50% of the protein in broiler diets was substituted with full-fat BSF larval meal instead of soybean cake (SBC), the birds' growth performance and carcass quality were severely harmed (Murawska *et al.*, 2021). According to a study by Kierończyk *et al.* (2023) that assessed the impact of adding BSFL at inclusion levels of 30g/kg, 60g/kg, and 90g/kg on carcass quality in place soybean sources, the fatty acid profile of the broilers' breast muscle was significantly impacted by the fat of *H. illucens* larvae as the inclusion level increased. Schiavone *et al.* (2018) conducted another experiment to assess the effects of partial (50%) and total (100%) replacement of soybean oil with BSFL fat on growth performance and carcass traits at the finisher stage. The results showed that neither partial nor total replacement of soybean oil with HI larva fat significantly affected growth performance indicators (final BW, ADG, FI, and FCR), with the exception of complete replacement, which produced better numerical values. Furthermore, there has been no significant variation in carcass characteristics or internal organ weight across diets.

2.5. Effect of Black Soldier Fly Larvae on Welfare of Broiler Chickens

Broiler welfare and production performance may be improved by adding black soldier fly larvae (BSFL) to their diets; however, the effects of dietary BSFL are probably dependent on how BSFL is supplied (Ipema *et al.*, 2022a). Broilers fed diets based on BSFLM showed no clinical symptoms of prevalent diseases. Feeding broiler quail growers BSF larval diet has no detrimental effects on mortality, according to Agunbiade *et al.* (2007) and Cullere *et al.* (2016). Moreover, gizzard erosion and toxicity were not observed in broiler diets derived from house fly larvae (Pretorius, 2011).

According to Abd El-Hack *et al.* (2020), there is no negative impact on mortality rates when bug meal is added to chicken feed ingredients. When broilers were given live BSFL as an environmental enrichment at 5% and 10% of the dry matter of their daily meal (four or seven times a day), their mobility, welfare, and avoidance of fearfulness were all improved without having an impact on their final body weight. However, it had a major impact on the FI for the whole period and the ADG at weeks three and four, whereas the 10% supplementation with repeated administration had the lowest FI and ADG (Ipema *et al.*, 2020).There is a lack of information and research on the optimal level of inclusion and substitution for conventional feed ingredients, as well as the economic significance, particularly in African nations, despite conflicting findings that the introduction of BSFL guaranteed good laying egg performance, overall meat quality and welfare, carcass characteristics, and good productive performances of broilers (Schiavone *et al.*, 2017a).

3. MATERIALS AND METHODS

3.1. Study Location

The production, processing and collection of black soldier fly larvae were done at the College of Natural and Computational Sciences (CNCS)of Addis Ababa University, Addis Ababa. The feeding experiment was done at private farm in Bishoftu city in the months of March and April/2025.The proximate analysis of the feed was conducted in Sal Alema laboratory and Alema koudijs nutrition laboratory using Near Infrared Spectroscopy (NIRS), while wet chemistry analysis for mineral content of feed was conducted in National Veterinary Institute (NVI), Bishoftu. Carcass characteristics evaluation was conducted in Alema slaughter house; drip loss and cook loss analysis of breast meat (*Pectoralis major*) was conducted in Veterinary Public Health (VPH) laboratory of the College of Veterinary Medicine and Agriculture (AAU), color and texture profile analyses of breast meat (*Pectoralis major*) were conducted in the Food Science Laboratory of Ethiopian Institute of Agricultural Research (EIAR), Bishoftu Research Center including proximate analysis of breast meat. The fat extraction of breast meat was done in insect chemical laboratory of the CNCS, Addis Ababa University.

Bishoftu is a City found in the Oromia Regional State situated at 47 km southeast of Addis Ababa at an altitude of 1900 m above sea level, latitude of 8 ^{o}44`N and longitude of 38$^{o}$ 57`E. It had a long rainy season from June to October and a short rainy season from March to May; the region has a bimodal rainfall pattern. The average (25 years) annual rainfall was 851mm with an average minimum and maximum temperature of 8.9^{o}C and 28.3^{o}C (mean 19^{o}C), respectively. The average relative humidity was 58.6% (CSA, 2018).

3.2. Animals and Management

A total of 156 one day-old Cobb-500 unsexed broiler chicks which were from 40 weeks old broiler breeders and had vaccinated against Marek's disease, Newcastle Disease (ND), Infectious Bronchitis (IB) and Infectious Bursal Disease (IBD) were received from Alema Farms, a well-known broiler day old chick (DOC) provider in Bishoftu City. The chicks were randomly allocated to four treatment groups having three replicates each (13 birds per pen) with a pen size of (1m*1.5m). The pens were well cleaned and disinfected with hydrogen peroxide and sodium hydroxide. The pens were bedded with *teff* straw of 5 cm depth. The chicks were weighed after randomly placing them in their respective pens and provided starter feed and supplemental vitamins together with drinking water as a means to alleviate stress. The lighting program was 24 hours of light the starter period and 18 hours of light during the grower and finisher phases (Cobb-vantress, 2022). Well curtained and guarded brooding areas were installed and one lamp of 200 watts was placed in each pen as a heater to bring room temperature of 33^0c for the first five days and it was decreased by 2^0C every other day to bring room temperature of 18^0C to 24^0Cby the 15^{th} day. As an additional heat source locally produced charcoals were used when needed; and when overheating was noticed outer curtains were opened to provide proper ventilation.

Each of the pens was equipped with one drinker and a feeder. Chicks were weighed at the start of the experiment and weekly afterwards. Feed and water were offered *ad lib* with a strong follow up to prevent shortage, spillage and wastage. Standard vaccination and management practices were strictly followed in rearing the birds, and as scheduled by the DOC dealer (Alema Farms), chicks were vaccinated against IB and ND at 12^{th} and 25^{th} day old via spray. The total numbers of experimental days for growth performance evaluation was 42.All data such as, daily feed consumption, feed left unconsumed after provided, mortality number, house temperature, relative humidity, type and route of vaccine provided, antibiotic and supplements supplied and other activities undertaken were recorded with a prepared format. Every management activity which is important for the growth of broilers was applied indifferently for all pens like supplemental vitamin provision, antibiotics treatment, anticoccidial treatment, water treatment and others.

3.3. Experimental Design and Diets

The study was arranged in a completely randomized design having four treatments each having three replications. The experimental diets were formulated using available ingredients as recommended by the breeding company for the strain(Cobb-vantress, 2022) by involving soybean cake as the main source of protein making references to dietary requirements of the chicks during the starter (0-14 days of age), grower (15-30 days of age) and finisher (31-42 days of age) phases. Then partial replacement of the soybean portion of the control feed with full fat BSFLM were made at 15, 30 and 45 % levels.

3.3.1. Black soldier fly larvae production, collection and processing

The larvae production and processing were done at the Insectarium of Insect Sciences Program Unit, Department of Zoological Sciences, AAU, Addis Ababa. The oviposition sites were made of an odorous substrate (usually fruit and vegetable leftovers from different restaurants) placed in a bowl, covered with cardboard strips and nets that prevent the entry of other flies. In general, females prefer laying eggs in dried small fissures. For this reason, pieces of cardboard were placed inside the cage for the purpose of oviposition. Eggs were collected from the oviposition sites twice a week. Masses of eggs were then be weighed and transferred into a small container having one cup of moisten wheat bran and incubated at 28^0 Celsius and 60% relative humidity for 3 to 5 days' to hatch.

After hatching, the small larvae hatchlings (first instar larvae) were transferred into larger culture plates containing moisten wheat bran for 5 days. After fifth day larger hatchlings (early instar larvae) were transferred to larger plates and horizontal ponds containing moist spent fruits and vegetables or restaurant leftovers which were provided *ad libitum* to allow a maximized growth throughout the growth period. Then, the late instar larvae were harvested (separated) from the substrate after 12^{th} day of hatching by sieving using a mash size of 1 to 4 mm and hand collection. In each plate, the substrate were pushed to one side of the box and left for a few minutes and then easily harvested (collected) at the bottom of the box where they had migrated (the substrate were removed progressively to allow the larvae migration and collection).

After harvesting, the larvae were immersed in to a boiled water at 100^0 Celsius for 3 minutes to kill the larvae and to avoid other unnecessary microbial and wastes. The immersed larvae were washed well and allowed to dry on direct sunlight in a greenhouse for 2 to 4 days based on the weather condition. Then the dried larvae were manually milled using a miller to make it flour and become ready for proximate analysis and ration formulation. As collection and processing were completed, the larvae were sent to Sal Alema laboratory for proximate analysis. As BSFLM is not available in the market to determine its exact price; its cost was estimated by summing up expenses for the purchase of wheat bran and other necessary items and equipment, the labor cost spent for the waste collection, colony follow up and larvae management, and rental cost of the production places, and water and electricity costs (Appendix 2). A total of 38 kg of dried larvae were used for the trial and it was produced using 0.5 kg of BSF egg, 47.5 kg of wheat bran and 672 kg of moist fruit, vegetable and kitchen food remnant wastes.

3.3.2. Other feed ingredients collection and preparation

Major feed ingredients like corn, soy bean cake, meat bone meal, wheat bran, lysine HCl, soybean oil, salt, broiler concentrate and wheat middling and bran were purchased from local markets in Bishoftu and their prices were used for the economic evaluation (Appendix 2). The proximate analysis for the feed ingredients was done in the laboratory of Alema Koudijs Feed PLC and Sal Alema laboratory, Bishoftu and the feed formulation was done using software called Feed Win version 0.24.1.0and the feed ingredients were mixed manually in the experiment site. The feed formulation considered for the energy, protein and other essential nutrient requirements for the Cobb 500 strain broiler chicken as recommended by the genetic company (Cobb-vantress, 2022). The feed formulation and nutrient requirements for the different experimental diets described in the table (Table 1).

3.4. Growth Performance Measurements

To determine daily feed intake, feed were weighed every afternoon (2:00 pm), using a digital balance and offered to the particular group. Feed refusal was collected next afternoon at similar time and weighed and feed intake for that particular day was calculated as the difference between offers and refusals for each replication, and total feed consumed in the pen was divided by the number of chicken in the pen used to determine daily feed intake per bird. Birds were weighed at the beginning of the experiment and then weekly per pen every (Wednesdays in the afternoon). Weight gain at different stages were calculated by weighing six birds per pen at $14^{th}$and 28^{th}, and the entire flock at the 42^{nd} days of age and Final Body weight gain (BWG) were calculated as the difference between the final (42^{nd} days) and initial body weights.

Average daily gain (ADG) was calculated as the ratio of BWG to the number of experimental days. Feed conversion ratio was computed as the ratio of feed consumption to BWG for the three growing stages. The mortality numbers were recorded daily and calculated as a percentage at the end of the experiment. Growth stages and Cumulative performances were evaluated at 14^{th}, 28^{th} and 42^{nd}days of age. The following parameters were evaluated: average daily feed intake (ADFI), body weight gain (BWG), feed conversion ratio (FCR), average daily gain (ADG).

3.5. Carcass Trait Evaluation

At the end of the feeding period (42 days of age of the birds), two birds were randomly selected from each replication based on average group weight, starved for 8 hours and sent to Alema poultry slaughter house for carcass yield and characteristics evaluation. The birds were labeled and weighed individually immediately before slaughtering. Then the birds were shackled and electrically stunned before killing and bled for about three minutes. Following bleeding, the birds were de-feathered after scalding in hot water for approximately two minutes, eviscerated, deboned and weighed accordingly. Dressed, cut and edible organ weights were calculated following the method outlined in Cobb 500 broiler commercial manual (Cobb-vantress, 2022).

Dressed carcass weights were measured after removal of blood and feather considering all edible parts as well as bone. Dressing percentage was calculated as the proportion of dressed carcass weight after removing blood, feather, kidney, lungs, pancreas, crop, proventriculus, small intestine, large intestine, caeca and urogenital tracts to live weight multiplied by one hundred. From dressed carcass drumsticks with thighs, breast meat, wings, liver, heart, gizzard, and neck, skin and back, were separated and weighed and their weights were divided by dressed weight and multiplied by 100 to determine percentage weight of each component.

3.6. Chemical and Physical Quality analysis of Breast Meat

After carcass yield evaluation 6 samples of breast meat from each treatment group were taken to CVMA's VPH laboratory for cook and drip loss analysis using ice box. Drip loss was measured by keeping uniformly shaped cuts of breast meat of 2 cm thick weighing 60-70 grams were placed in zipped bags and hanged by strings to avoid surface contact for 24 hours at 4 °C and calculated as a percentage of weight loss during storage (Funaro *et al.*, 2014). Previously dripped samples were weighed and used for cook loss determination. Cooking loss was determined by weighing the breast meat before and after cooking. Meats were enveloped in an aluminum foil and cooked in an electric oven at 100 °C for 15 min, and then samples were removed from the oven and left to cool at room temperature and calculated as percentage of weight difference before and after cooking (Lin *et al.*, 2014).

Six breast meat samples from each treatment were taken for the physical characteristic analysis. The color profile of lightness (L*), redness (a*) and yellowness (b*) was measured by a reflectance colorimeter (Konica Minolta chromameter, CR-400-model, Japan) on raw breast meat. The device was calibrated with black and white standards before meat color determination (da Silva *et al.*, 2017). Texture profile analysis (TPA) was done using BROOKFIELD CT3 texture analyzer machine (MODEL CT3 10K). Proximate analysis for Protein (kjeldhal method), fat (soxhlet extraction) , moisture (oven drying at 105 degrees for 18 hours) and ash content (muffle furnace burning at 560 degrees for 6 hours) of raw breast were done from 3 samples of each treatment. Samples for proximate analysis were frozen until analyzed at the food science laboratory of EIAR, Bishoftu. Protein, fat, and ash contents were measured following a standard methodology (AOAC, 1995).

3.7. Economic Efficiency Analysis

The calculation of the production cost during the experimental period served as the foundation for the economic parameters of broiler production. After 42 days of fattening, the actual body weight was used to calculate the manufacturing cost. The gross return was calculated as the cost of broiler sold at the end, net return (NR) calculated as the difference between gross return and the cost incurred for the purchase of day old chicks and feed (other running costs are neglected as they are similar for all treatments), net profit margin (NPM) calculated as net profit divided by total revenue multiplied by 100, benefit cost ratio (BCR) calculated as total revenue divided by total cost, and economic efficiency (EE) calculated as net profit divided by total cost (Olomu, 1995).

3.8. Statistical Analysis

All data were recorded on data record sheet and exported to excel spread sheet and it were subjected to a one-way and cruscal walli's ANOVA with experimental diet (TR0 (C), TR1 (HI15), TR2 (HI30) and TR3 (HI145) as fixed effect) analyzed using Rstudio version 4.3.1 for starter, grower, finisher and final body weights, average daily gain, FCR, feed cost/kg weight, carcass yields, physical parameters, and proximate compositions as responsive variables. The significance between treatment means was tested at a statistical significance level of 5% where significant, separated using Tukey's and dunn's multiple comparison procedure.

The model for determining the dietary substitution effect on performance, carcass characteristics and economic efficiency was as follows:

$Y = \beta_0 + \beta_1 C + \beta_2 TR1 + \beta_3 TR2 + \beta_3 TR3 + \varepsilon$

Where Y: is the dependent variable to be evaluated

β_0: the intercept value, ε: the error

β_1, β_2… coefficient values

TR0, TR1, TR2, TR3 are the independent variables (substitution levels)

3.9. Ethics Approval

Ethical guidelines were applied to all aspects of production, farming, transport, and humane killing. The welfare of birds during the entire experimental period were assured considering the five freedoms of animals. Every procedure related to animal handling and their routine manipulations was carried out according to the animal care guidelines and protocols approved by the CVMA animal ethics committee approval number VM/ERC/04/17/025, 25/02/2025.

4. RESULTS

4.1. The Feed Formulation and Proximate Analysis Results

Least cost and commonly available ingredients were used for the feed formulation (Table 1). As indicated in the table (Table 2) except variations in the amounts of BSFLM and SBC all other ingredients were similar across all treatment groups. The proximate analysis result for CP shows 20-20.9 %, 18.7-18.9% and 17.3-17.9% respectively for starter, grower and finisher feeds. The AME for the three growing phase feeds was 3150-3220 for starter, 3174-3255 for grower and 3232 to 3330 Kilo calories/Kg for finisher feeds. Treatments with higher level of BSFLM contained higher amount of EE and the CF level is below 4% in all feed types and the DM is from 91 to 92.3 %. The ash content is lower in TR1 at starter phase but other feeds as well as treatment groups have comparable ash content.

Table 1: Near-Infrared Spectroscopy (NIRS) results of proximate composition for feed ingredients used for ration formulation and their market prices

No	Ingredient name	DM	EE	CP	CF	CA	Price/kg (birr)
1	BSFLM	96.6	26.5	41.24	3.5	5.6	90.5
2	Soybean cake	96.9	6.2	47.0	5.2	7.1	63
3	Wheat middling	90.5	4.2	13.3	6.9	3.2	35
4	Maize	87	3.7	7.1	2.4	1.3	32
5	Wheat bran	89.6	4.2	13.3	9.5	4.3	25
6	meat bone meal	88.4	16.2	33.6		34.8	63
7	Broiler Concentrate						320
8	Lysine HCl						350
9	salt						30
10	Soybean Oil						320

DM- dry matter, EE- ether extract, CP- crude protein, CF- crude fiber, CA- crude ash, BSFLM- black soldiers fly larvae meal

Table 2: The ingredient list and proximate composition of experimental diets

treatments / feed(kg	Starter phase (mash)				Grower phase (mash)				Finisher phase (mash)			
	TR0	TR1	TR2	TR3	TR0	TR1	TR2	TR3	TR0	TR1	TR2	TR3
maize	59.2	59.2	59.2	59.2	63	63	63	63	65	65	65	65
WB	2	2	2	2	1.83	1.83	1.83	1.83	1.48	1.48	1.48	1.48
WM	2	2	2	2	4	4	4	4	3.4	3.4	3.4	3.4
SBC	29	24.7	20.4	15.9	25.5	21.7	17.9	14.1	24.5	20.8	17.2	13.48
BC	2.75	2.75	2.75	2.75	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Lysine	0.04	0.04	0.04	0.04	0.16	0.16	0.16	0.16	0.11	0.11	0.11	0.11
salt	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SO	1	1	1	1	0	0	0	0	1	1	1	1
MBM	4	4	4	4	3	3	3	3	2	2	2	2
BSFLM	0	4.35	8.7	13.1	0	3.83	7.65	11.5	0	3.68	7.35	11.03
Total	100	100	100	100	100	100	100	100	100	100	100	100
AME	3150	3190	3210	3220	3208	3174	3255	3202	3232	3259	3330	3310
DM	92.3	92	92.1	92	91.3	91.2	91.3	91.2	91.3	91.2	91.0	91.4
CP	20.9	20.4	20.9	20	18.8	19.0	18.7	18.7	17.9	17.9	17.5	17.3
EE	6	7.1	9.1	9.4	5.2	6.4	7.1	8.1	6	7.1	7.7	8.7
CF	3.4	3.6	3.8	3.4	2.8	2.9	2.5	3.1	2.7	2.6	2.2	2.2
CA	6.53	3.67	6.34	6.16	7.56	5.39	5.09	5.04	5.5	5.6	5.5	5.8

WB- wheat bran, WM- wheat middling, SBC- soybean cake, BC- broiler concentrate, SO- soybean oil, MBM- meat bone meal, BSFLM- black soldiers larvae meal, AME- apparent metabolisable energy, DM- dry matter, CP- crude protein, EE- ether extract, CF- crude fiber, CA- crude ash

4.2. Effect on Growth Performance

Over the course of 42 days and three distinct growing stages, this study found that a 15% substitution of BSFLM (TR1) for soybean cake maintained better body weight (BW) and average daily gain (ADG) compared to the control (TR0) group but without significant variation; however, higher substitution levels (30% and 45%) resulted in a decrease in growth performance, as shown in (Table: 2).While feed intake and feed conversion ratio were similar across treatments and did not exhibit any significant variations at this early stage, starter phase (1–14 days), body weight gains and average daily gain were marginally greater in the group fed 15% BSFLM (TR1) and TR3 has the least WG as well as ADG. Average daily feed intake was higher inTR1 while FCR was improved in TR2 but it was worse in the control group, though not significant.

The birds in TR1 continued to have the highest body weight and average daily gain as they entered the grower phase (15–28 days), while the birds in the highest replacement group (TR3) performed least in ADG as well as ADFI, while the differences were not statistically significant. Although there was once more no significant change, TR1's feed conversion ratio showed a trend of improvement. While birds on higher BSFLM inclusion diets (TR2 and TR3) left behind. Birds on the control diet (TR0) and those on TR1 maintained greater body weights and weight gains during the finisher phase (29–42 days). Unlike the starter and grower phases TR0 has better performance than TR1 in all parameters in the finisher phase. During all phases, feed consumption and FCR varied just slightly without any significance, with TR1 continuing to have a little improvement. Interestingly, birds in TR0 and TR1 had far greater final body weights and daily gains by the end of the trial (1–42 days) than those in TR3, though feed intake and feed conversion ratio showed no significant variation, high BSFLM inclusion (45%) had the lowest daily feed intake and FCR.

Table 3: Effects of partial substitution of soybean cake with black soldiers fly larvae meal in broiler chickens diets on growth performance

Growth phases	Treatments Parameters	TR0	TR1	TR2	TR3	SEM	P
Starter (1-14)	IW (g)	41	39	40	41.3	0.473	0.298
	BW(g/bird)	293	302	287.33	281.67	5.417	0.5997
	ADG(g/bird)	20.928	21.57	20.52	20.12	0.387	0.5997
	ADFI(g/bird)	28.57	29.15	27.39	27.25	1.833	0.9806
	FCR	1.4	1.35	1.34	1.35	0.028	0.984
Grower (15-28)	BW(g/bird)	662.83	697.14	667.03	616.17	15.243	0.3111
	ADG(g/bird)	47.34	49.79	47.64	44.01	1.089	0.3115
	ADFI(g/bird)	80.02	78.05	76.145	72.48	3.096	0.855
	FCR	1.7	1.57	1.6	1.65	0.053	0.445
finisher (29-42)	BW(g/bird)	1087.56	1078.124	1017.183	1003.282	19.188	0.3006
	ADG(g/bird)	77.68	77	72.66	69.94	1.574	0.254
	ADFI(g/bird)	140.2	137.1	135.67	133.93	3.025	0.767
	FCR	1.80	1.78	1.87	1.92	0.0475	0.63
overall (1-42)	BW(g/bird)	2042.7[a]	2077.63[a]	1985.5[ab]	1900.95[b]	19.70	0.0084
	ADG(g/bird)	48.64[a]	49.46[a]	47.27[ab]	45.89[b]	0.44	0.022
	ADFI(g/bird)	82.93	81.43	79.74	77.88	3.77	0.958
	FCR	1.70	1.65	1.69	1.70	NA	0.4101

Means in a row with no/similar superscript are not significantly different (p>0.05), IW-initial weight, BW- body weight, ADG-average daily gain, ADFI-average daily feed intake, FCR-feed conversion ratio, TRO- control feed with no soybean cake substituted by black soldiers fly larvae meal (BSFLM), TR1- trial feed with 15% soybean cake substituted by BSFLM, TR2-trial feed with 30% soybean cake substituted by BSFLM, TR3- trial feed with 45% soybean cake substituted by BSFLM

4.3. Effects on Carcass Traits

The growth performance patterns were reflected in the carcass characteristics, where the carcass weight, dressing percentage and live weight at slaughter showed a similar tendency, with TR1 displaying the highest weights and TR3 the lowest (Table 3). A measure of the amount of usable meat, the dressing percentage, was considerably higher in TR0 and TR1 but lower in TR2 and TR3. Although the proportions of drumstick, thigh, wing, liver, heart, gizzard, and bone/skin remained largely unchanged throughout treatments, the yield of breast meat significantly lower in TR3.

Table 4: Effects of partial substitution of soybean cake with black soldiers fly larvae meal in broiler diets on carcass characteristics of broiler chickens

	Experimental groups				SEM	p-value
Carcass characteristics	TR0	TR1	TR2	TR3		
Live weight at slaughter (g)	2183^{ab}	2315^{a}	2167^{ab}	1964^{b}	36.87	0.006
Dressed carcass weight (g)	1665^{ab}	1767^{a}	1615^{ab}	1460^{b}	29.13	0.056
Dressing percentage (%)	76.27^{a}	76.31^{a}	74.5^{b}	74.5^{b}	0.35	0.002
Breast percentage (%)	23.11^{a}	22.62^{a}	22.24^{a}	20.1^{b}	0.453	0.03
Drumstick percentage (%)	12.43	12.5	12.3	12.6	0.155	0.92
Thigh percentage (%)	15.3	15.52	16.55	16.45	0.337	0.47
Wing percentage (%)	9.67	10.2	10.3	10.4	0.123	0.15
Liver percentage (%)	2.35	2.50	2.41	2.28	0.078	0.78
Heart percentage (%)	0.71	0.83	0.79	0.84	0.033	0.55
Gizzard percentage (%)	2.23	2.13	2.27	2.52	0.067	0.21
Bone and skin percentage (%)	33.24	32.68	32.16	33.6	0.456	0.71

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

4.4. Effect on Proximate Composition of Breast Meat

Crude protein levels in relation to the nutritional content of breast meat were the same in all groups, indicating that BSFLM had no effect on protein content (Table 4). Crude fat levels, however, exhibited a non-linear trend, being substantially lower in TR1 and highest in TR2. There were minor differences in the total ash content and moisture content; TR1 had the lowest ash and the highest moisture content, whereas TR3 had the lowest moisture content (Table 4). The meat's nutritional profile was not significantly changed by these variations.

Table 5: Effects of partial substitution of soybean cake with black soldiers fly larvae meal in broiler diets on proximate composition of breast meat

Proximate composition	Experimental groups				SEM	p-value
	TR0	TR1	TR2	TR3		
Crude Protein (%)	23.73	23.7	23.8	23.2	0.59	0.99
Crude fat (%)	8.04^{a}	6.28^{b}	8.31^{a}	7.32^{ab}	0.42	0.044
Total ash (%)	4.51	3.74	4.15	4.18	0.16	0.49
Moisture (%)	73.33^{ab}	74.7^{a}	74^{ab}	72.67^{b}	0.41	0.016

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

4.5. Effect on Water Holding Capacity, Texture and Color of Breast Meat

The BSFLM incorporation levels had no effect on the physical characteristics of the breast meat, including cohesion, hardness, springiness, and drip loss (Table 5). Adhesion and cook loss, on the other hand, were reduced in all BSFLM treatments and greater in the control group. However, color parameters revealed significant variations: TR1 and TR2 showed less redness, TR2 and TR3 showed a considerable rise in yellowness, and TR3 showed the maximum lightness.

Table 6: Effects of partial substitution of SC with BSFLM in broiler chickens diets on water holding capacity, texture profile analysis and color of breast meat of broilers

Physical parameters	Experimental diets				SEM	p-value
	TR0	TR1	TR2	TR3		
Drip loss (%)	3.48	4.04	3.67	3.27	0.203	0.654
Cook loss (%)	28.6[a]	25.6[ab]	23.4[b]	26.2[a]	0.754	0.0009
Hardness-1	4129	3100	3894	3135	564	0.902
Hardness-2	3332	2543	3228	2591	493	0.936
Cohesiveness	0.52	0.50	0.53	0.50	0.013	0.753
Springiness	3.43	3.27	3.33	3.30	0.141	0.984
Adhesion	1.5[a]	0.83[b]	0.83[b]	0.77[b]	0.16	0.052
Redness (a*)	3.13[a]	2.53[b]	2.54[b]	2.68[ab]	0.18	0.04
Yellowness (b*)	0.39[a]	0.29[a]	1.0[b]	1.66[b]	0.29	0.000
Lightness (L*)	43.70[a]	44.81[ab]	44.2[ab]	46[b]	0.562	0.025

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

4.6. Effect on Economic Efficiency of Broiler Production

As evidenced from the graph below (Graph 1), In TR1, the cost of feed per kilogram of carcass was considerably lower compared to TR2 and TR3. This pattern points to a U-shaped trend, with greater inclusion levels (30% and 45%) resulting in higher costs, while mild BSFLM substitution of 15% (TR1) for soybean cake decreased feed cost per kg carcass in comparison to the control. The cost per kilogram of dressed carcass follows the live weight trend showing lowers costs in TR0 and TR1.With the largest carcass weight (1.76 kg), net return (307.72 birr), and economic indicators (BCR: 2.20, NPM: 54.6%, EE: 120.44%), TR1 performed the best. Feed intake marginally declined, maintaining the overall feed cost per bird despite growing feed costs across treatments. The lowest carcass yield and lowest economic return were produced by TR3, which had the greatest feed price. Profitability and biological performance are enhanced by moderate BSFLM incorporation, as is probably the case in TR1.

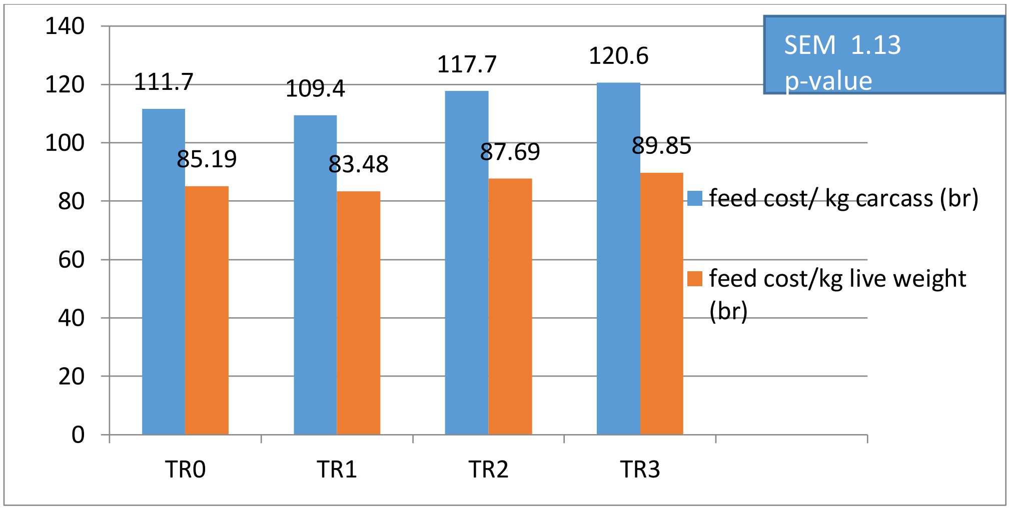

Figure 1: Effects of partial substitution of soybean cake with black soldiers fly larvae meal in broiler diets on feed cost per kg of live and carcass weight

Table 7: Price of the formulated feed in different phases and treatment groups and economic efficiency analysis parameter result

Feed type and prices (birr)	Treatments				Remarks
	TR0	TR1	TR2	TR3	
starter	53.08	54.27	55.47	56.66	
grower	48.53	49.58	50.64	51.69	
finisher	50.64	51.65	52.66	53.67	
Average cost of feed/kg	50.25	51.31	52.34	53.41	
Feed consumed (kg)	3.48	3.42	3.35	3.27	
Cost of feed (birr)	175.02	175.48	175.36	174.66	
Cost of DOC (birr)	80	80	80	80	
Total cost (birr)	255.02	255.48	255.36	254.66	
Carcass weight/bird (kg)	1.66	1.76	1.61	1.46	
Total return (birr)	531.2	563.2	515.2	467.2	320 birr /kg
Net return (birr)	276.18	307.72	259.84	212.54	
Benefit cost ratio	2.08	2.20	2.02	1.83	
Net profit margin (%)	52	54.6	50.4	45.5	
Economic efficiency (%)	108.3	120.44	101.76	83.46	

5. DISCUSSIONS

5.1. The Feed Formulation and Proximate Analysis

The formulated feed fulfills the protein and the energy requirements of cobb-500 broiler chicks in all the growing stages (Cobb-vantress, 2022). Starter feed of TR0 has relatively higher protein content and lower AME than other groups. This is due to the fact that the crude protein content of SBC is slightly higher (47%) than that of BSFLM (41.24%). The higher amount of AME is found in higher substitution levels (TR2 and TR3) which is due to the higher ether extract (EE) in BSFLM (26.5%) than that of SBC (6.2%). Despite the slight variations in both energy and crude protein levels, the nutrients available fulfills the requirements of cobb-500 broiler chickens (Cobb-vantress, 2022)

5.2. Effect on Growth Performance

According to the results of the current study, over the course of 42 days, a 15% substitution of BSFLM (TR1) for soybean cake maintained slightly higher body weight (BW) and average daily gain (ADG) than the control group (TR0) and TR2, and significantly higher than TR3. Higher levels of substitution (30% and 45%), however, resulted in lower growth performance. Kithama *et al.* (2023) discovered that whereas complete replacement resulted in decreased performance, partial replacement (up to 25%) had no significant effect on growth. Furthermore, closely related results were published by Onsongo (2017) whose broiler diets contained up to 15% BSFLM, Bellazza Oddon *et al.* (2021), who added up to 5%, Dabbou *et al.* (2021), who replaced up to 6% of soybean oil with BSFLO, and Moula *et al.* (2018), who added 2% defrosted fresh larvae, did not find any significant effects on the broilers' growth performance parameters (ADG, FCR, DFI and BWG) throughout all growing phases. Strengthening result was reported by who replaced up to 30% of soybean meal with BSFLM and concluded that BSFL meal can be included up to 22.5 % in broiler finisher diets because a higher level of inclusion results in poorer growth performance and FCR was optimal at 15% inclusion (Domitila *et al.*, 2024).

The current findings imply that while greater levels of BSFLM may be detrimental, moderate replacement and inclusion levels in soybean products can maintain growth performance, especially BW and ADG. These maintained as well as a little improved weight gains may be through provision of medium-chain fatty acids for rapid energy, antimicrobial peptides and chitin that improve gut health, and high-quality protein with a good amino acid balance for broilers the BSF larvae offered. Complete and large replacements, however, may impair performance because of excess chitin, an imbalance in amino acids, and possible problems with digestibility (Schiavone *et al.*, 2017b; (Ipema *et al.*, 2022 b).

5.3. Effect on Carcass Traits of Broiler Chickens

In the present study, the 15% BSFLM addition (TR1) improved carcass yield and dressing percentage just slightly as compared to the control. Nevertheless, lower carcass weight and corresponding dressing percentages were the outcome of increased substitution rates (30% and 45%).Bellazza Oddon *et al.* (2021), Dabbou *et al.* (2021), Schiavone *et al.* (2018), La Mantia *et al.* (2024), Murawska *et al.* (2021), and Brah *et al.* (2024) have reported that a partial (less than 20%) substitution of soybean products to black soldiers fly larvae products (meal and oil) resulted in comparable and slightly higher slaughter weight, dressed weight, dressing percentage, and breast percentage when compared to control diets. Additionally, the yields on the aforementioned parameters were significantly lower as substitution and inclusion levels increased. Balolong *et al.* (2020) found that adding BSFLM to broiler chicken diets up to 100% reduced the dressing percentage value but had no significant effect on it (73% control against 70% in 100% inclusion). These results highlight how crucial it is to substitute soybean products with BSFLM at optimal inclusion levels in order to preserve carcass characteristics. This could be because of the balanced and high-quality amino acid composition of BSFLM, which at moderate inclusion and substitution levels in animal diets can improve protein deposition and encourage the formation of lean tissue (Makkar *et al.*, 2014).

Chitin, a structural polymer found in the exoskeletons of BSFLM, can limit growth performance by reducing nutrient use and reducing nutrient digestibility at high inclusion rates (Schiavone *et al.*, 2016). Furthermore, too much BSFLM may change the composition of the gut microbiota and affect immunological responses, which could divert energy from building muscle and reduce growth efficiency (Cheng *et al.*, 2023).In lower levels it decreases body fat and produce leaner meat in broilers which help improve dressing weights (Murawska *et al.*, 2021).

5.4. Effect on Proximate Composition of Breast Meat

All treatments showed statistically no change in crude protein content; indicating that up to 45% substitution of BSFLM for soybean cake has not any significant effect on meat protein content. This result is consistent with the reports by Biasato *et al.* (2018), Balolong *et al.* (2018), and Cullure *et al.* (2019), who found that the balanced amino acid profile of BSFLM preserved muscle protein levels in broilers. Additionally, the stable protein content shows that protein deposition and muscle growth were unaffected at this inclusion levels. This suggests that the amino acid profile of BSFL is not led the feed to imbalances in protein levels of feed and having balanced amino acids in the feed lead to proper deposition of proteins in the muscle compared to the control diet (Lu *et al.,* 2022).

Significant variation was seen in the crude fat content, with TR1 having the lowest fat content (6.28%), which was significantly different from TR0 (8.04%) and TR2 (8.31%). The fatty acid profile of BSFLM, which is high in medium-chain fatty acids like lauric acid, which are known to affect lipid metabolism and lessen fat deposition in tissues, may be the cause of the fat reduction in the 15% BSFLM inclusion (Spranghers *et al.*, 2017). Complex interactions between energy metabolism, fat deposition, and other dietary lipid sources may be reflected in the variability at higher inclusion levels. Contrary to this finding, reports by Balolong *et al.* (2018) and Cullure *et al.* (2019) indicated that using

BSFLM in place of soybean has no noticeable impact on the fat content of breast meat, with the exception of slightly higher fat contents at higher inclusion levels. Significantly high content of fat in TRO might be due to the *de novo* synthesis of fats in the liver from extra carbohydrates and proteins due to the slight higher content of starch and protein in soybean cake compared to the insect meal (Menezes *et al*., 2013).

Soybean and black soldier fly (BSF) larvae can both be mineral sources, however they may have different effects on muscle mineralization. Calcium and phosphorus are abundant in BSF larvae, and SB also supplies these minerals (Edea *et al*., 2022).The control group (TR0) had the greatest ash level, whereas TR1 had the lowest without having significant differences. In contrast to the current finding, Balolong *et al.* (2018) and Cullure *et al.* (2019) reported lower ash contents of 1.22% and 1.18%, respectively, in the control and 50% inclusion groups with no significant differences Because soybean and insect meal have different mineral content and bioavailability, the addition of BSFLM may have reduced the amount of ash in the breast meat as it is noticed from the proximate result of BSFLM having lower ash content than soybean cake and also mineral absorption may be affected by the chitin concentration(Schiavone *et al.*, 2016).Transport in the cell and absorption of minerals from the diet of broilers affect mineral accumulation in poultry muscle tissue (Edea *et al*., 2022).

There were significant variations in the moisture content, with TR1 having the highest percentage, TR0 and TR2 being in the middle, and TR3 having the lowest percentage. This result is closely related to the findings of Balolong *et al.* (2018) and Cullure *et al.* (2019), who reported moisture contents of 76% and 71-75%, respectively, with no significant changes. Since fat and moisture usually have an inverse relationship in muscle tissue, a higher moisture level in TR1 is associated with a lower fat content (LawrieandLedward, 2006). Meat's sensory characteristics may be improved by the increased moisture with moderate BSFLM incorporation, which could increase juiciness and tenderness (Jisang, 2021). This finding discloses that while moderate and lower substitution of soybean by BSFLM does not affect its moisture content while higher

(45%) substitution level increases its dryness, suggesting a shift in its moisture characteristics (Fatima *et al*., 2023).

5.5. Effect on Water Holding Capacity, Texture and Color of Breast Meat

The non-significant changes in drip loss (P = 0.654) in this investigation showed that substituting BSFLM at different amounts for soybean cake had little effect on the meat's ability to hold water. With the exception of TR2, cook loss did not differ significantly downward in the BSFLM and control groups, This implies that the ability of meat to retain moisture during processing is not negatively impacted by mild BSFLM as well as higher incorporation and may even be somewhat enhanced as the highest loss is recorded in TR0. The water-holding capacity (drip loss and cook loss) of breast meat was not significantly affected by a 50–100% substitution of BSFLM for soybean, according to similar findings published by Cullure *et al.* (2019) and Murawska *et al.* (2021) as well as the report of Bederuddin *et al*. (2024) does not show any significant effect of BSFL inclusion at a level up to 12% in replacement for soybean meal but, in contrast to this finding the higher losses were recorded in the 12% inclusion group.

According to Mancini and Hunt (2005), feed composition might affect meat's ability to retain water, which is essential for meat juiciness and customer acceptability. By supplying premium proteins and hydrophilic chitin, which increase muscle structure and moisture retention, BSFLM raises the water-holding capacity (WHC) of broiler meat (Makkar *et al.*, 2014; Kroeckel *et al.*, 2012: Aprianto *et al.*, 2023). Better WHC is indirectly supported by its high fatty acid profile, especially lauric acid, and antioxidant components, which also help to maintain muscle integrity and lower oxidative stress (Mwaniki *et al.*, 2020; Spranghers *et al.*, 2018).

In the current study, there were no statistically significant variations in hardness values between treatments, according to the texture profile analysis result of meat samples. This implies that adding up to 45% BSFLM does not change the meat's firmness. This result is consistent with other studies by Biasato *et al.* (2019) and Srikha *et al.* (2024), which found that adding insect meal had no significant impact on the hardness of broiler meat, suggesting that the structural integrity of muscle fibers remained substantially unchanged. There was no significant difference between treatments in cohesiveness, which measures the internal connection inside the meat matrix (p=0.753).This implies that independent of BSFLM levels, meat retains its elasticity and degree of cohesiveness during measurement and chewing. This cohesiveness stability is consistent with research by Huff-Lonergan and Lonergan (2005), who found that while dietary protein sources can affect muscle texture, cohesiveness may not be significantly impacted by mild feed composition changes. Further evidence that muscle elasticity was maintained across diets came from the fact that springiness, which measures the meat's capacity to regain its shape after deformation, was likewise unchanged (P = 0.984). This is in line with Mancini and Hunt's (2005) findings that, in the absence of major nutritional imbalances, muscle elastic characteristics are resistant to mild dietary changes.

The BSFLM-fed groups (TR1, TR2, and TR3) had considerably lower adhesion values than the control group (TR0), with a trend toward significance indicated by P = 0.053. Reduced adhesion implies that the addition of BSFLM reduces the meat's surface stickiness, or how much it sticks to surfaces (or perhaps oral tissues) while being eaten. According to Wang *et al.* (2017), who documented diet-induced variations in meat texture parameters related to feed composition, this might be the consequence of minor alterations in muscle surface proteins or connective tissue characteristics impacted by the fatty acid profile or chitin content of the diet.

The BSFLM-fed groups TR1 and TR2 had significantly lower levels of redness (a*), which measures the intensity of red pigmentation mostly caused by myoglobin concentration, than the control TR0 (P = 0.04). The redness values of breast meat (1.57–6.77) reported by Lee *et al.* (2025), Cullere *et al.* (2019), Gross-BOŠKOVIĆ *et al.* (2024), and Srikha *et al.* (2024) are consistent with current finding. However, the inclusion of black soldier fly larvae at varying inclusion levels did not significantly alter the broiler diet when used in place of soybean products. A lower myoglobin concentration or alterations in its chemical state, which can be impacted by dietary composition, may be indicated by decreased redness (Mancini and Hunt, 2005). Similar decreases in redness, possibly as a result of changed muscle oxidative metabolism or antioxidant status, have been noted in broilers fed insect meal diets (Biasato *et al.*, 2018).

The higher BSFLM inclusion groups showed a substantial increase in yellowness (b*) (P < 0.001). This result is consistent with that of Cullere *et al.* (2019), who found that the yellowness value of breast meat rose as the inclusion level increased, but that the value was higher (12.9–14.5) and did not significantly changed. However, GROSS-BOŠKOVIĆ *et al.* (2024), Srikha *et al.* (2024), Lee *et al.* (2025), and Murawska *et al.* (2021) reported much lower values in higher inclusion groups, and higher yellowness (2.08-19.07) values than the results of the current study. This could be because the meal of black soldiers fly larvae was used in place of other substances, which have higher carotid values. However, the deposition of pigments like carotenoids or lipids present in BSFLM, which are known to give tissues yellow colors (Wang *et al.*, 2017), and the lower values of pigments in soybean cake may be the cause of the increase in yellowness as inclusion increases in the current finding. Because insect diets are high in medium-chain fatty acids and pigments that can build up in muscle, elevated yellowness may also be linked to alterations in lipid content or fatty acid composition (Spranghers *et al.*, 2017).

The TR3 group's lightness (L*), which measures the meat's brightness, was noticeably higher than that of the TR0 control group (P = 0.025). This finding contradicts the findings of Cullere *et al.* (2019), Gross-BOŠKOVIĆ *et al.* (2024), and Lee *et al.* (2025), who found non-significantly greater lightness values in broiler chicken control diets. Reduced myoglobin content or modifications to the shape and water-holding capacity of muscle fibers are frequently associated with increased lightness (Mancini and Hunt, 2005). The reduced redness and enhanced fat oxidation, which impact muscle pigment stability, may also be connected to the paler hue seen in this discovery at higher BSFLM levels.

5.6. Effect on Economic Efficiency

When BSFLM is included at a modest level (15% replacement), the cost per kilogram of carcass shows a decreasing trend from TR0 (111.7 birr) to TR1 (109.4 birr), suggesting a potential economic gain. Feed costs are not the source of the decrease in feed costs per kilogram of carcass or live weight. The cost of BSFLM is higher than that of soybean cake (Appendix 1 and 2), (63 birr for SBC *vs.* 90.5 birr for BSFLM), and the cost per kilogram of feed for all three phases of feed (starter, grower, and finisher) is lower in the control group than in the substituted groups (Appendix 3). The cost also rises as the rate of substitution increases. Although Leipertz *et al.* (2024) and Brah *et al.* (2024) reported that supply shortages and their cost conceal the widespread use of insect meals like BSFLM as a replacement for plant-based conventional feed sources, Affedzie-Obresi *et al.* (2020) reported the economic benefit of including BSFLM by partially (21%) substituting soybean products.

The increased final live weight, dressing weight, dressing %, and feed efficiency in TR0 and TR1 contributed for the decreased cost per kilogram of carcass. But when BSFLM was added at 30% and 45%, the price per kilogram of carcass was increased again in addition to higher feed costs per kilogram of feed at these groups (Table 7). This suggests that higher levels of BSFLM have resulted in decreased growth performance and feed efficiency, raising the cost per unit of weight gain and carcass weight, which aligns with findings from other studies that indicate diminishing returns at elevated inclusion rates of alternative protein sources (Schiavone *et al.*, 2016).

Important information about feed utilization and profitability can be gleaned from the economic and performance analysis of broiler diets given diets with rising feed costs, which may represent varying degrees of Black Soldier Fly Larvae Meal (BSFLM) inclusion in place of SBC. Due to a decrease in feed intake from 3.48 kg in TR0 to 3.27 kg in TR3, the total feed cost per bird stayed reasonably consistent (range from 174.66 to 175.48 birr), even though the average feed cost per kilogram increased gradually from 50.25 birr in TR0 to 53.41 birr in TR3. This inverse link between feed cost and intake is in line with research by Makkar *et al.* (2014) and Dabbou *et al.* (2018), who found that BSFLM can lower feed consumption without sacrificing intake of vital nutrients because it is more nutrient-dense than conventional plant protein sources. The peak carcass weight in TR1 was 1.76 kg, indicating that a moderate amount of BSFLM inclusion may maximize growth and nutrient utilization. This is consistent with research by Mwaniki *et al*. (2020) and Bovera et al. (2016) that found that broilers fed BSFLM-based diets had better weight gain and feed conversion, especially when inclusion rates were kept below 50%.The decrease in carcass output in TR3 (1.46 kg) suggests that too much BSFLM inclusion may have a detrimental effect on growth, maybe as a result of chitin content or an imbalance in amino acids, as noted by Barragan-Fonseca *et al*. (2017).

Financially speaking, overall returns peaked in TR1 (563.2 birr) and declined in TR3 (467.2 birr), reflecting the trend in carcass weight. This diet produced the most profitable results, as evidenced by the largest net return (307.72 birr) and the best economic indicators, including the benefit-cost ratio (2.20), net profit margin (54.6%), and economic efficiency (120.44%), which were also noted in TR1. This finding is consistent with the findings of Gariglio *et al.* (2019) and Cullere *et al*. (2016), who found that the optimal amounts of BSFLM incorporation enhance economic performance by optimizing return on investment and reducing dependency on traditional protein sources such as soybean meal. On the other hand, TR3, which had the lowest carcass yield and the greatest feed cost, had the worst economic metrics, highlighting the necessity of carefully adjusting the levels of BSFLM incorporation. According to these results, BSFLM can be a good substitute protein source for broiler diets; however, its effectiveness hinges on balancing inclusion rates to guarantee both biological performance and financial efficiency.

8. CONCLUSION AND RECOMMENDATIONS

The present study demonstrated that partial substitution of soybean cake (SBC) up to 15% with black soldier fly larvae meal (BSFLM) in broiler chicken diets can maintain or non significantly enhance growth performance, carcass characteristics, and meat quality while offering economic advantages in terms of BCR, EE and NPM. Meat quality parameters such as crude protein, water-holding capacity, and texture were not negatively affected, although color changes were observed at higher inclusion rates. The findings highlight the potential of BSFLM as a sustainable alternative protein source in broiler production, offering nutritional benefits. However, excessive substitution levels (above 15%) may compromise performance and profitability, suggesting the need for careful optimization of inclusion and substitution rates.

Based on the above conclusion the following recommendations are forwarded:

- Since including BSFLM at levels higher than 15% substitution for soybean cake may negatively affect broiler growth performance and economic returns it should be further investigated.
- Developing more cost-effective and scalable production methods for BSFLM to enhance its commercial availability, sustainability and affordability needed.
- Investigations are needed on the environmental benefits of BSFLM, including its potential to reduce organic waste in poultry production.
- Promoting the development of policy frameworks and educational initiatives that support the adoption of insect-based proteins, such as BSFLM, in poultry diets to ensure sustainable and efficient production.

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8. APPENDICES

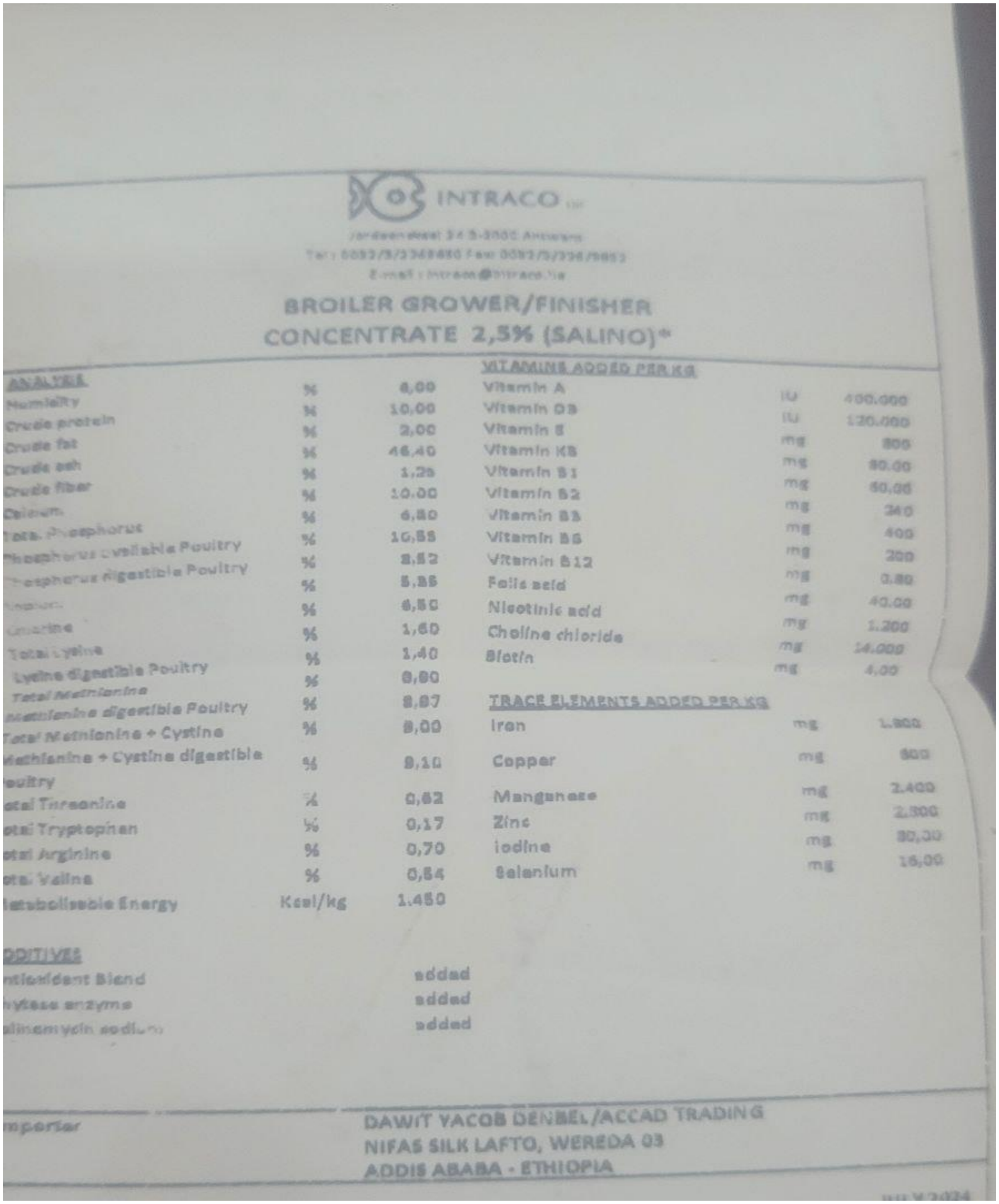
Appendix 1: Pictures showing on farm Feed mixing and farm management

Appendix 2: Items and materials used, and estimated cost of them for 1 kg of dried BSFLM production

no	Materials and items used	Amount	Unit	Unit price (birr)	Total price (birr)	Remarks
1	Wheat bran	1.25	kg	25	31.25	
2	Labor cost	2	pcs	12	24	
3	Purchase of materials (plates, ponds and others)	0.1	pcs	250	25	
4	Electricity and water	1	kg	4.5	4.5	
5	Rent of production site	1	kg	5.75	5.75	
6	total				90.5	

Appendix 3: Picture showing Farm preparation and evaluation of the installed brooding facilities

Appendix 4: Composition of broiler concentrate used for ration formulation



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BROILER GROWER/FINISHER
CONCENTRATE 2,5% (SALINO)*

ANALYSES		
Humidity	%	8,00
Crude protein	%	10,00
Crude fat	%	2,00
Crude ash	%	46,40
Crude fiber	%	1,25
Calcium	%	10,00
Total Phosphorus	%	6,80
Phosphorus available Poultry	%	10,55
Phosphorus digestible Poultry	%	2,52
Sodium	%	5,35
Chlorine	%	6,50
Total Lysine	%	1,60
Lysine digestible Poultry	%	1,40
Total Methionine	%	0,80
Methionine digestible Poultry	%	0,87
Total Methionine + Cystine	%	0,00
Methionine + Cystine digestible Poultry	%	0,10
Total Threonine	%	0,62
Total Tryptophan	%	0,17
Total Arginine	%	0,70
Total Valine	%	0,54
Metabolisable Energy	Kcal/kg	1.450

VITAMINS ADDED PER KG		
Vitamin A	IU	400.000
Vitamin D3	IU	120.000
Vitamin E	mg	800
Vitamin K3	mg	80.00
Vitamin B1	mg	60,00
Vitamin B2	mg	340
Vitamin B3	mg	400
Vitamin B6	mg	200
Vitamin B12	mg	0.80
Folic acid	mg	40.00
Nicotinic acid	mg	1.200
Choline chloride	mg	14.000
Biotin	mg	4,00

TRACE ELEMENTS ADDED PER KG		
Iron	mg	1.800
Copper	mg	800
Manganese	mg	2.400
Zinc	mg	2.300
Iodine	mg	30,00
Selenium	mg	16,00

ADDITIVES	
Antioxidant Blend	added
Phytase enzyme	added
Salinomycin sodium	added

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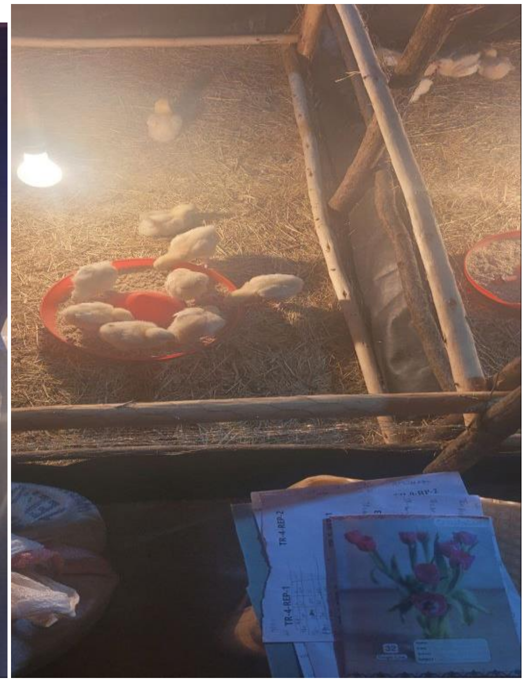
Appendix 5: Pictures during egg collection of black soldiers fly

Appendix 6: Feeding, collection, killing and drying of black soldiers larvae

Appendix 7: Pictures showing partial farm practices



Appendix 8: Pictures showing carcass traits evaluation

Appendix 9: Pictures showing physical and chemical quality evaluation of meat

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ADDIS ABABA UNIVERSITY
College of Veterinary Medicine
and Agriculture
Bishoftu

Animal Research Ethical Review Committee

Ethical clearance certificate

Certificate Ref. No: VM/ERC/04/75/17/2025

Name of Applicant: **Abdulkaf Kemal** (DVM, MSc student)

Address: Department of Microbiology, Parasitology and Poultry Health, College of Veterinary Medicine and Agriculture, Addis Ababa University

Title of the project: *Partial Soybean cake replacement with black soldier fly larvae: effect on performance, carcass traits, breast meat attributes and economic efficiency of broilers*

Date of application:	**December, 2024**
Nature of the project:	**Experimental trial**
Target animal species:	**Chicken**
Number of animals involved:	**156**
Study area:	**Bishoftu, Ethiopia**

Minutes No. and date of review: **VM/ERC/04/17/025, 25/02/2025**

The Institutional Animal Care and Use Committee of the College of Veterinary Medicine and Agriculture of the Addis Ababa University has reviewed the above research project and unanimously approved the application of Abdulkaf Kemal.

The Federal Democratic Republic of Ethiopia
Addis Ababa University College of Veterinary Medicine and Agriculture

Professor Getachew Terefe (DVM, PhD)
Chairman

Signature

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Addis Ababa University
College of Veterinary Medicine and Agriculture
Department of Microbiology, Parasitology and Poultry Health

"The Effects of Substituting Parts of Soybean Cake with Black Soldier Fly (*Hermetia illucens*) Larvae in Broiler Chick Diets on Growth Performance and Carcass Traits"

A Thesis submitted to the College of Veterinary Medicine and Agriculture of Addis Ababa University in partial fulfillment of the requirements for the degree of Masters of Science in Poultry Health and Management

BY:
Abdulkaf Kemal

Advisor: Ashenafi Mengistu (PhD, Associate Professor)

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Addis Ababa University College of Veterinary Medicine and Agriculture Department of Microbiology, Parasitology and Poultry Health "The Effects of Substituting Parts of Soybean Cake with Black Soldier Fly (Hermetia illucens) Larvae in Broiler Chick Diets on Growth Performance and Carcass Traits" A Thesis submitted to the College of Veterinary Medicine and Agriculture of Addis Ababa University in partial fulfillment of the requirements for the degree of Masters of Science in Poultry Health and Management BY: Abdulkaf Kemal Advisor: Ashenafi Mengistu (PhD, Associate Professor) Co-advisors: Yitbarek Woldehewariyat (PhD, Associate Professor) Araya Gebresilassie (PhD, Associate Professor) June, 2025 Bishoftu, Ethiopia ABSTRACT By 2050, there will be about 9.7 billion people on the planet, which needs sustainable, efficient and alternative sources of proteins to feed animals that used for human consumption. This study evaluated the effects of replacing soybean cake (SBC) in broiler chicken diets with black soldier fly larvae meal (BSFLM) in terms of growth performance, carcass characteristics, meat quality and economic efficiency. A total of 156 Cobb-500 broiler day old chicks were assigned to four treatments: control (TR0), 15% (TR1), 30% (TR2), and 45% (TR3) BSFLM replacement levels for SBC. Over a 42- day feeding period, TR1 (15% substitution) produced the highest final body weight (2,077.6 g) and average daily gain (49.5 g/day), significantly outperforming TR3 (1,900.9 g; 45.9 g/day) ($p < 0.05$). Feed conversion ratios remained optimal at 1.65 in TR1, while higher substitution levels (TR2 and TR3) resulted in performance decline. Carcass yield reflected growth trends, with TR1 showing superior live weight at slaughter (2,315 g) and dressed weight (1,767 g), and the highest dressing percentage (76.3%), compared to TR3 (1,964 ; 1,460 g; 74.5%) ($p < 0.05$) but it has not shown any significant differences from TR0 and TR2.

Meat quality analyses revealed no significant differences in crude protein content (~23.7%), but a marked reduction in crude fat was observed in TR1 (6.3%) compared to TR0 (8.0%) ($p = 0.044$). Drip loss (3.5–4.0%), cook loss (23.4– 28.6%), and textural properties (hardness, springiness, cohesiveness) were consistent across treatments, although higher BSFLM levels resulted in minor alterations in meat colors, lightness (L*) increased (up to 46.0 in TR3), redness (a*) decreased (2.5 in TR1/TR2 vs. 3.1 in TR0), and yellowness (b*) increased at higher inclusion levels. Economic analysis demonstrated that TR1