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"Effects of replacing fish meal with partially defatted black soldier fly (Hermetia illucens) larvae meal on growth performance and carcass characteristics of broiler chickens"

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Abstract

Black soldier fly (Hermetia illucens) larvae meal has gained considerable attention as a sustainable alternative protein source for poultry diets. However, information on the optimum level of replacement of fish meal with partially defatted black soldier fly larvae meal (PDBSFLM) in broiler diets remains limited. This study evaluated the effects of graded replacement of fish meal with PDBSFLM on growth performance and carcass characteristics of broiler chickens. A total of 150 one-day-old Ross 308 broiler chicks were randomly allocated to five dietary treatments consisting of 0, 25, 50, 75, and 100% replacement of fish meal with PDBSFLM. Each treatment had three replicates of 10 birds and the feeding trial lasted 35 days. Feed intake, body weight gain, feed conversion ratio (FCR), and dressing percentage were determined. Dietary treatment significantly affected all measured parameters ($p < 0.05$). Broilers fed the diet containing 25% PDBSFLM recorded the highest feed intake (772.29 g), body weight gain (211.76 g), and dressing percentage (90.76%), as well as the most efficient FCR (3.65). Performance and carcass yield declined as the level of fish meal replacement increased beyond 25%. Complete replacement of fish meal resulted in the lowest growth performance and dressing percentage (62.26%). The results indicate that partial replacement of fish meal with PDBSFLM can improve broiler productivity and carcass yield, whereas excessive inclusion may negatively affect performance. Under the conditions of this study, replacement of fish meal with PDBSFLM at 25% was the most effective level for supporting growth and carcass development. These findings demonstrate the potential of partially defatted black soldier fly larvae meal as a sustainable alternative protein ingredient in broiler nutrition.

Keywords: Hermetia illucens, alternative protein, insect-based feed, broiler chickens, carcass yield, poultry nutrition.

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Introduction

Poultry production is among the fastest-growing livestock sectors worldwide and plays a critical role in providing high-quality animal protein to the rapidly increasing human population. Global demand for poultry meat continues to rise due to population growth, urbanization, increasing incomes, and changing consumer preferences toward affordable and nutritious animal protein sources (Van Huis *et al*., 2013). Broiler chicken production is particularly important because of its rapid growth rate, efficient feed conversion, short production cycle, and widespread consumer acceptance (Mottet & Tempio, 2017). However, feed costs account for approximately 60–70% of total production expenses in poultry enterprises, with protein ingredients such as fish meal and soybean meal representing a substantial proportion of these costs (Khan *et al*., 2016; Veldkamp & Bosch, 2015). The increasing cost and limited availability of conventional protein sources, coupled with environmental concerns associated with their production, have intensified the search for sustainable alternative feed ingredients (Makkar *et al*., 2014; Sánchez-Muros *et al*., 2014). Insects have recently gained considerable attention as alternative protein sources for animal feeding because of their high nutritional value, efficient feed conversion, and ability to utilize organic waste streams for biomass production (Van Huis, 2013; Rumpold & Schlüter, 2013). Furthermore, insect farming requires less land, water, and energy than conventional livestock production systems, making it environmentally sustainable (Surendra *et al*., 2016; Singh & Kumari, 2019).

Among the insect species evaluated for animal feeding, black soldier fly (*Hermetia illucens*) larvae have emerged as one of the most promising alternatives for poultry nutrition (Makkar *et al*., 2014; Gold *et al*., 2018). Black soldier fly larvae meal contains high levels of crude protein, lipids, essential amino acids, minerals, and bioactive compounds that can support growth and health in poultry (Makkar *et al*., 2014; Schiavone *et al*., 2017). In addition, black soldier fly larvae can efficiently convert organic waste into valuable protein-rich biomass, contributing to circular economy approaches in livestock production systems (Diener *et al*., 2011; Lalander *et al*., 2018). Several studies have demonstrated that black soldier fly larvae meal can partially replace conventional protein sources such as fish meal and soybean meal without negatively affecting broiler performance (Schiavone *et al*., 2017; Dabbou *et al*., 2018). Moderate inclusion levels have been associated with improved feed intake, body weight gain, and feed conversion efficiency due to the favorable amino acid profile and digestibility of black soldier fly larvae meal (Attia *et al*., 2017; de Souza Vilela *et al*., 2021). Additionally, the presence of medium-chain fatty acids, particularly lauric acid, may contribute to improved gut health and nutrient utilization in broiler chickens (Khan, 2018; Shumo *et al*., 2019). Despite these advantages, the level at which black soldier fly larvae meal can effectively replace fish meal in broiler diets remains a subject of investigation. High inclusion levels may reduce nutrient digestibility due to the presence of chitin, a structural polysaccharide found in the insect exoskeleton, which may limit nutrient availability and growth performance when included in excessive amounts (Makkar *et al*., 2014; Oonincx *et al*., 2015). Previous studies have reported inconsistent results regarding growth performance and carcass characteristics at high inclusion levels, indicating the need to establish optimal replacement rates under different production conditions (Dabbou *et al*., 2018; Schiavone *et al*., 2019). Therefore, this study was conducted to evaluate the effects of graded replacement of fish meal with partially defatted black soldier fly (*Hermetia illucens*) larvae meal on feed intake, body weight gain, feed conversion ratio, and dressing percentage of broiler chickens. It was hypothesized that partial replacement of fish meal with black soldier fly larvae meal would improve growth

Materials and Methods

The statement of Animal Rights

The materials and procedures of this study were approved by the Egerton University Research and Ethics Committee, with approval number EUISERC/APP/596/2026 and the National Council for Science and Technology of Rwanda under the research permit number NCST/482/0019/2026.

Study Site

The study was conducted at the farm located in College of Agriculture, Animal Science and Veterinary Medicine, the University of Rwanda, and in laboratories of department of Food Sciences and Technology for a period of 35 days. The university is located in Northern province, Musanze District in Rwanda, at longitude from 29°37’59’’E to 29°37’75’’E and latitude between 1°30’06’’S to 1°30’94’’S and (Akinyemi, 2017). It has a moderate tropical climate with a temperature between 15°C and 18°C and the average annual rainfall is around 1845 mm (72.6 inch) (REMA, 2011).

Insect Meal Preparation

Sun-dried black soldier fly (BSF) larvae were procured from a company, Agrivis Ltd., located in Kenya. The larvae were ground using a hammer mill fitted with a 2–3 mm screen to obtain a uniform particle size suitable for broiler feeding and subsequently partially defatted. The defatting process was carried out using an automatic screw oil press machine, which operates by applying friction and continuous pressure generated by a rotating screw to compress the BSF material. During the process, the oil passes through small openings in the press chamber while the solid material is retained. The pressed solids are subsequently discharged as a hardened cake from the machine. The partially defatted BSF larvae meal was then mixed with other feed ingredients to formulate the experimental diets.

Experimental diets, animals, Design and Treatments

The experimental diets (Table 1) were formulated to be iso-nitrogenous and iso-energetic, with crude protein (CP) levels maintained at approximately 19.5% and metabolizable energy (ME) at approximately 3100 kcal/kg. The diets were formulated to meet or exceed the nutrient requirements of broiler chickens as recommended by the National Research Council (NRC, 1994) and Cobb 500 breeder guidelines (Cobb-Vantress, 2022). A single-phase feeding program was implemented throughout the 35-day experimental period. The calculated nutrient composition of the diets was based on standard feed composition tables (NRC, 1994). Five dietary treatments were formulated by progressively replacing fish meal with partially defatted Black Soldier Fly (*Hermetia illucens*) larvae meal (PDBSF) at 0, 25, 50, 75, and 100% replacement levels. The ingredient composition and calculated nutrient contents of the experimental diets are presented in Table 1

Table 1. Composition of the Experimental Diets for Broiler Chicks in g/100g

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Ingredients (g/100g)	T0	T1	T2	T3	T4
Maize	55	53.8	52.5	51.5	50.5
Wheat pollard	5.0	4.0	3.5	2.5	1.4
SBM	25	26.5	28	29.5	31.1
FM	10	7.5	5.0	2.5	0
PDBSFL	0	2.5	5	7.5	10
Vegetable oil	3.0	3.5	4.0	4.5	5.0
Iodized salt	0.3	0.3	0.3	0.3	0.3
DCP	1.1	1.1	1.1	1.1	1.1
Limestone	0.3	0.3	0.3	0.3	0.3
Premix	0.3	0.3	0.3	0.3	0.3
Total	100	100	100	100	100
Calculated ME(Kcal/Kg)	3100	3105	3102	3100	3103
Calculated CP (%)	19.5	19.5	19.6	19.5	19.6

FM = Fish meal; BSFL = Partially Defatted Black Soldier Fly larvae meal; SBM = Soybean meal; DCP = Dicalcium phosphate; ME = Metabolizable energy; CP = Crude protein.

The experiment followed a Completely Randomized Design (CRD) with five treatments, each replicated three times. Each replicate consisted of 10 birds, making a total of 30 birds per treatment. Feed was offered daily at 09:00 hours in clean feeders, and refusals were collected and weighed prior to the next feeding to determine feed intake.

Birds Management

A total of 150 one-day-old Ross 308 broiler chicks were obtained from a commercial hatchery (Easy Hatch Ltd.). Upon arrival, the chicks had been vaccinated against Newcastle disease and Infectious Bronchitis at the hatchery. Subsequently, Gumboro (Infectious Bursal Disease) vaccinations were administered on days 7 and 14, followed by a Newcastle disease booster vaccination on day 21 (Department of Livestock Services, 2024). The birds were housed in a well-ventilated poultry facility equipped with electrical heating and continuous fluorescent lighting. Prior to chick placement, the house was thoroughly cleaned and disinfected, and fresh wood shavings were provided as litter material. At the beginning of the experiment, all chicks were individually weighed using a digital balance (±0.01 g) and randomly allocated to five dietary treatments in a Completely Randomized Design (CRD). Each treatment was replicated three times, with 10 birds per replicate, giving a total of 30 birds per treatment and 150 birds overall. The experimental house was divided into 15 pens (1.2 m × 1.2 m), corresponding to the 15 experimental units. During the brooding period, ambient temperature was maintained between 30 and 34°C using infrared lamps. Birds had ad libitum access to feed and clean drinking water throughout the 35-day experimental period. Feed was offered daily at 09:00 h in clean feeders, and feed refusals were collected and weighed before the next feeding to determine feed intake. The health status of the birds was monitored daily. During the study, ten birds died as a result of an accidental charcoal stove incident and were excluded from subsequent performance analyses.

Data Collection

Growth Performance

The experimental period lasted 35 days. Data collected included feed intake, body weight, and carcass characteristics. From these measurements, growth performance parameters were calculated as follows:

- Feed Intake (FI): Determined as the difference between feed offered and feed refused (Abebe & Tamir, 2016).
- Body Weight Gain (BWG): Calculated as the difference between final and initial body weight.
- Average Daily Gain (ADG): Calculated as BWG divided by the number of days (Chehade *et al*., 2022).
- Feed Conversion Ratio (FCR): Calculated as the ratio of average daily feed intake to average daily gain (Brah *et al*., 2018).

Slaughter Procedure

At the end of the experiment (day 35), three birds per replicate were randomly selected, individually weighed, and fasted for 12 hours with access to water before slaughter. A total of 15 birds (three per treatment) were used for carcass evaluation. Birds were humanely slaughtered following international animal welfare guidelines (FAO; OIE). Prior to exsanguination, birds were electrically stunned to ensure immediate unconsciousness. Stunning effectiveness was confirmed by the absence of reflexes, including corneal reflex and rhythmic breathing. The carotid arteries and jugular veins were severed using a sharp knife to allow complete bleeding (3–5 minutes). After confirmation of death, carcasses were scalded at 60°C for 2 minutes, defeathered, washed, and eviscerated (FAO, 2019).

- Dressing percentage was then calculated: Calculated as Dressed carcass weight (weight of the slaughtered bird after removal of feathers, blood, head, feet, and internal organs) divided by live body weight (weight of the bird before slaughter) times a hundred

$$\text{Dressing Percentage (\%)} = \frac{\text{Dressed Carcass Weight}}{\text{Live Body Weight}} \times 100$$

RESULTS AND DISCUSSION

Results

The effects of replacing fish meal with partially defatted black soldier fly larvae meal (PDBSFLM) on feed intake, body weight gain (BWG), feed conversion ratio (FCR), and dressing percentage of broiler chickens are presented in Table 2 and Figure 1. Dietary treatment significantly influenced all measured performance parameters ($p < 0.05$). Broilers fed the diet containing 25% PDBSFLM (T1) exhibited the highest feed intake, body weight gain, dressing percentage, and the most efficient feed conversion ratio compared with the other treatments. Birds receiving higher inclusion levels of PDBSFLM (75% and 100%) showed reduced feed intake, body weight gain, and dressing percentage. These findings suggest that moderate replacement of fish meal with PDBSFLM can enhance growth performance and carcass yield, whereas excessive inclusion may negatively affect broiler productivity.

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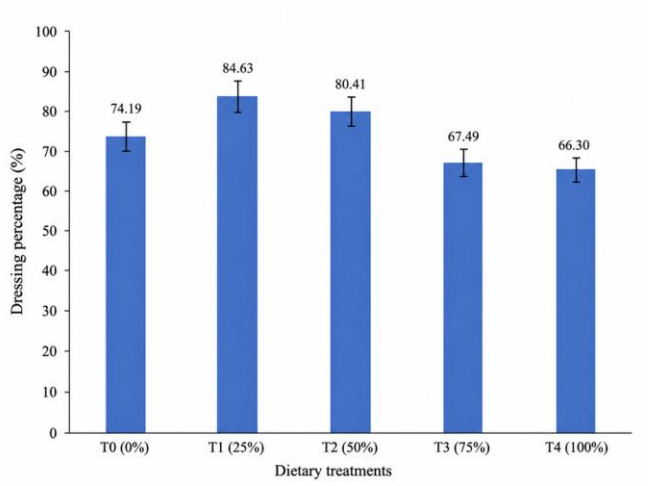
Table 2: Effect of Dietary Treatment on Feed Intake (g/d), Body Weight Gain (g/d) and Feed Conversion Ratio of Chickens

Nutrients			Means			SEM	p-value
	T0	T1	T2	T3	T4		
Intake	484.2^{c}	772.29^{a}	603.07^{b}	412.64^{cd}	341.21^{d}	39.35	<.0001
BWG	82.39^{cd}	211.76^{a}	110.10^{b}	85.27^{c}	75.16^{d}	5.21	<.0001
FCR	5.87^{d}	3.65^{a}	5.48^{c}	4.84^{bc}	4.54^{b}	0.02	0.003

^{abcd}Means in a row with different superscript letters are significantly different (P< 0.05);

T0: feed without partially defatted black soldier fly larvae, T1: normal feed with 25% of partially defatted black soldier fly larvae, T2: feed with 50% partially defatted black soldier fly larvae, T3: feed with 75%partially defatted black soldier fly larvae and T4: feed with 100% partially defatted black soldier fly larvae.

Figure 1: Effect of dietary treatments on dressing percentage of chickens



Dressing percentage followed a similar trend, with the highest values observed at 25% inclusion, while higher levels resulted in reduced carcass yield.

Discussion

The present study evaluated the effects of graded replacement of fish meal with partially defatted *Hermetia illucens* larvae meal (BSFLM) on the growth performance and carcass characteristics of broiler chickens. The dietary treatments consisted of increasing substitution levels of fish meal: 0% (T0), 25% (T1), 50% (T2), 75% (T3), and 100% (T4). The results revealed significant effects of dietary treatment on feed intake, body weight gain (BWG), feed conversion ratio (FCR), and dressing percentage, indicating that the level of PDBSF inclusion plays a crucial role in determining broiler performance.

Feed Intake

Feed intake varied significantly among treatments, with the highest intake observed in birds fed the 25% PDBSF diet (T1: 772.29 g) and the lowest in those fed the 100% replacement diet (T4: 341.21 g). The increased intake at moderate inclusion levels suggests that partial replacement of fish meal with PDBSF enhances diet palatability and acceptability. This may be attributed to the favorable sensory characteristics and lipid composition of PDBSF, which can stimulate voluntary feed consumption. The present findings are in agreement with several studies that have reported positive effects of BSF inclusion at moderate levels. For instance, De Souza Vilela *et al*., (2021) reported that inclusion of BSF at approximately 20% improved broiler performance, while Attivi *et al*., (2020) found that a 10% inclusion level enhanced feed intake, average daily gain, and feed efficiency. Previous studies have shown that partial replacement of conventional protein sources with black soldier fly larvae meal does not adversely affect feed intake or growth performance when diets are balanced for energy and protein (Biasato et al., 2020; Schiavone et al., 2017).

Conversely, the reduced feed intake observed at higher inclusion levels (T3 and T4) may be due to decreased palatability, increased chitin content, or changes in diet texture. High inclusion levels of insect meal have been associated with reduced voluntary feed intake when diets are not adequately balanced (Makkar *et al*., 2014; van Huis, 2020). These findings suggest that while BSF is acceptable at moderate levels, excessive inclusion may negatively affect feed consumption.

Body Weight Gain (BWG)

Body weight gain followed a similar trend, with birds fed the 25% PDBSF diet (T1) exhibiting the highest BWG (211.76 g), while those in the control (T0) and 100% replacement group (T4) showed lower gains. The superior growth performance at moderate inclusion levels suggests improved nutrient utilization and efficient protein deposition. This may be explained by the high-quality protein and favorable amino acid profile of BSF, including essential amino acids such as lysine and methionine, which are critical for muscle development (Makkar *et al*.,2014, Attia *et al*., 2017). Additionally, BSF contains bioactive compounds such as lauric acid, which may enhance gut health and nutrient absorption, thereby supporting growth. However, the decline in BWG at higher inclusion levels (≥50%) may be attributed to reduced nutrient digestibility associated with chitin, as well as potential imbalances in amino acid availability when fish meal is completely replaced (Makkar *et al*., 2014). Similar findings have been reported in several studies. For instance, Dabbou *et al*., (2018) observed a quadratic response in growth performance, where BWG improved at moderate inclusion levels (5–10%) but declined at higher levels (15%). Likewise, Schiavone *et al*., (2017, 2019) reported that performance may decrease when inclusion exceeds approximately 15–20%, especially if diets are not adequately balanced for essential amino acids and energy. Nevertheless, Dalmoro *et al*., (2025) demonstrated that inclusion levels of 5–15% may not consistently enhance growth under certain conditions. These results confirm that excessive substitution may negatively affect broiler performance and highlight the importance of optimizing inclusion levels.

Feed Conversion Ratio (FCR)

Feed conversion ratio results further support the existence of an optimal inclusion level. Birds fed the 25% PDBSF diet (T1)

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recorded the lowest FCR (3.65), indicating superior feed efficiency compared to other treatments. This suggests that moderate inclusion of BSFLM allows for more efficient conversion of feed into body mass. In contrast, FCR increased progressively at higher inclusion levels (T2–T4), indicating reduced efficiency. This trend may be explained by lower nutrient digestibility at high insect meal inclusion levels, particularly due to chitin, which can limit nutrient availability and utilization (Oonincx *et al*., 2015). Furthermore, inadequate balancing of dietary energy and essential amino acids at high substitution levels may contribute to poorer feed efficiency (Makkar *et al*., 2014). Interestingly, the control diet (T0) exhibited a higher FCR compared to T1, suggesting that partial replacement of fish meal with PDBSF may enhance feed utilization efficiency beyond conventional diets (Attia *et al*., 2017). These findings reinforce the importance of using BSFLM at optimal inclusion levels to maximize feed efficiency.

Dressing Percentage

Carcass evaluation revealed that dressing percentage was significantly influenced by dietary treatment, with the highest values observed at the 25% inclusion level (T1). This improvement may be associated with enhanced protein deposition and overall growth efficiency at moderate inclusion levels of BSF larvae meal. However, a decline in dressing percentage was observed at higher inclusion levels (≥50%), likely due to reduced nutrient digestibility and absorption, which may impair muscle development. Similar findings have been reported by De Souza Vilela *et al*., (2021), who observed improved carcass yield at moderate inclusion levels of approximately 20% BSFLM, but reduced performance at higher inclusion levels. Recent studies also support these findings. With Saidani *et al*., (2025) who observed positive effects at moderate inclusion levels of 5% and 10%. In addition, Dalmoro *et al*., (2025) also reported improved carcass yield and gut health at inclusion levels between 5% and 15%, emphasizing the role of efficient nutrient utilization in carcass development. Conversely, high inclusion levels may negatively affect carcass traits due to reduced nutrient availability, increased chitin content, and metabolic inefficiencies, particularly when diets are not adequately balanced for essential nutrients (Makkar *et al*., 2014; van Huis, 2020).

Conclusion

Partial replacement of fish meal with partially defatted black soldier fly larvae meal significantly affected broiler performance and carcass yield. The 25% replacement level produced the highest feed intake, body weight gain, dressing percentage, and the most efficient feed conversion ratio. Higher replacement levels reduced performance, suggesting that excessive inclusion may limit nutrient utilization. Therefore, PDBSFLM can be considered a sustainable alternative protein source in broiler diets, with a 25% replacement of fish meal recommended under the conditions of this study.

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Author contribution:

Clarisse Uwimbabazi conceptualized the study, conducted the experiment, performed data analysis, and drafted the manuscript. Anthony M. King'ori, James O. Ondiek, and Marie Goretti Umuhoariho supervised the research, contributed to study design, and critically reviewed the manuscript. All authors approved the final version.

Conflict of Interest

The authors declare no conflict of interest.

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